Australian Government
Department of Defence
Defence Science and Technology Organisation

Time Critical Targeting Concept of Operations (CONOPS) Interactions

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DSTO-TR-2543

ABSTRACT

In this paper, we consider Concept of Operations (CONOPS) for engaging Time Critical Targets (TCTs) and quantify the feasibility of those CONOPS. The process involves defining the scope of the CONOPS, developing a plausible TCT CONOPS based on existing practices, and simulating the dynamics of the CONOPS to obtain a better understanding of the inherent interactions within such a complex, dynamic and concurrent system involving people, sensors, and computational processing. Further, we consider a case study of the undertaking of the complete TCT CONOPS from a Multi-Sensor Command and Control Aircraft (MC2A) and the implications for crew structure. This work should be of interest to those working on TCTs, Command and Control (C2) systems, and surveillance and reconnaissance issues. While the examples presented here are USAF-centric, the techniques proposed should be applicable to a wide range of C2 problems where response time is a critical factor.

RELEASE LIMITATION

Approved for public release

Published by

Air Operations Division
DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

AR-014-987
May 2011

APPROVED FOR PUBLIC RELEASE

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Executive Summary

In 2003, RAND Project Air Force examined the applicability of proposed surveillance assets for engaging Time Critical Targets. The targets examined in this work included elusive ground-based vehicles, such as missile Transporter-Erector-Launchers (TEL). A key question to be answered was what surveillance capability would be required to undertake this task over a large area and for an extended period. The overall effort examined the proposed Space-Based Radar (SBR) and air breathing assets, such as Global Hawk and the Multi-Sensor Command and Control Aircraft (MC2A), utilising the Multi-Platform Radar Technology Insertion Program (MP-RTIP) for performing surveillance. Both Ground-based Moving Target Indicator (GMTI) and Synthetic Aperture Radar (SAR) modes were used to find, track, image, and geo-locate vehicles. Work was also undertaken to understand the communication loads that these technologies would require in a medium to high threat environment. That research can be found in RAND TR-159. The work presented here complements these other studies.

Time Critical Targeting (TCT) will form one of the most important strike roles in future operations. The links between initial surveillance through classification, targeting, strike and Battle Damage Assessment (BDA) is documented by the Concept of Operations (CONOPS). In this paper, we aim to understand and develop a CONOPS for TCT, and test the dynamic interactions that are implicit within this operational structure. For example, we include the following components within the CONOPS:

- Operational Roles: here we define the operators and the roles they will be undertaking. This also includes the hierarchy of command between operators.
- Operational Tasking: we define the actual tasks that will be performed by operators. This includes the operation, which operator performs the task, the amount of time each task will take, and the start and end states that result from each task.
- Tasking Priorities: we describe the priority between different task types. If a single operator has to undertake a number of different tasks, the priority will most likely be different, requiring one task to be completed before another.

From this understanding of CONOPS structure a complete, if idealised, CONOPS is developed given the assumed scenario and the assumed capabilities. These include a Multi-Sensor Command and Control Aircraft (MC2A) with Multi-Platform Radar Technology Insertion Program (MP-RTIP) sensor, Global Hawk aircraft and Space-Based Radar (SBR), all operating Ground Moving Target Indicator (GMTI) and Synthetic Aperture Radar (SAR) sensors. A dynamic simulation of the interactions between operators undertaking the CONOPS tasking was then developed.

After providing a baseline for comparison we have examined the effect of modifying the CONOPS timings; both classification speed and decision-making speed. Reducing the time required for decision-making in some manner reduces the overall scenario length but also leads to a greater than expected reduction in the time spent by identified targets queuing for the decision process to begin. Reducing the time required for GMTI classification reduces the overall simulation time, the workload on analysts and significantly reduces the time vehicles wait for analyst action. Further flow-on effects result in a decrease in the amount of SAR imagery required and hence a reduction in the workload of the Sensor Controllers. Increasing classification speed also flows on to the Mission Commander: extending the wait-time for targets without affecting the overall mission commander workload, simply because targets are identified faster. We also examined the external environment: changing vehicle numbers and their movement rate. A linear increase in the number of vehicles results in a greater than linear increase in processing time for non-targets, while target kill-chains increase at a less than linear rate. More importantly the wait-time attributed to analysts increases drastically, with the flow-on effect of increasing the need for SAR classification. This may result in a greater than expected loading on communications. A reduced number of changes from stationary to moving and vice versa also reduces the loading on analysts by lessening the need for SAR to be employed for classification, and to a lesser extent for mensuration. Further work examines the potential crewing requirements of the MC2A aircraft, given a larger number of vehicles to track and identify. By examining the largest delays relating to individual operators, we increase the crew size to obtain an average target prosecution rate of under an hour.

The simulation capability presents a best-case analysis of the use of the CONOPS. The dependence on a large number of assumptions — number of vehicles, time of appearance, rate of change of movement, number of operators and command structure, the tasks performed by each operator, the length of time to complete each task, and so on — means that the relation between the specific results and a final operational CONOPS is tenuous. The value of these experiments is in determining the causal links between variables, how specific delays influence the overall completion of the TCT role, and stimulating discussion into whether these characteristics will have operational consequences or whether they are spurious results, possibly based on ill-formed CONOPS specifications.

Overall the benefits of this approach to CONOPS development and subsequent testing are:

- To encourage the development of complete CONOPS for undertaking specific tasks, determining whether the definition is logically complete and thus generally plausible.
- To consider the CONOPS specifics through particular assets for a particular scenario to determine whether the scenario solution is feasible under a static instantiation.
- To allow the execution of the specific CONOPS using particular crews to give a rough indication of whether the CONOPS is dynamically feasible given the scenario constraints.

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Contents

Abbreviations

AC	Analyst Coordinator
AOC	Air Operations Center
ATO	Air Tasking Order
ATR	Automatic Target Recognition
BDA	Battle Damage Assessment
C2	Command and Control
C2BM	Command and Control Battle Management
CAOC	Combined Air Operations Center
CONEMP	Concept of Employment
CONOPS	Concept of Operations
CONUS	Continental United States
COP	Common Operating Picture
CPN	Colored Petri Net
DCGS	Distributed Common Ground Station
ELINT	Electronic Intelligence
EOIR	Electro-Optical Infra-Red
GH	Global Hawk
GMTI	Ground Moving Target Indicator
HRR	High Range Resolution
HUMINT	Human Intelligence
IMINT	Imagery Intelligence
IPB	Intelligence Preparation of the Battlefield
ISR	Intelligence, Surveillance and Reconnaissance
ISRC	ISR Coordinator
JFACC	Joint Force Air Component Commander
LACM	Land Attack Cruise Missile
LEO	Low Earth Orbit
MAAP	Master Air Attack Plan
MASINT	Measurement and Signals Intelligence
MC	Mission Commander
MC2A	Multi-Sensor Command and Control Aircraft
MP-RTIP	Multi-Platform Radar Technology Insertion Program
MTC	Mobile Target Coordinator
OODA	Observe, Orient, Decide, Act
SA	Situational Awareness
SAM	Surface to Air Missile
SAR	Synthetic Aperture Radar
SBR	Space Based Radar
SenCont	Sensor Controller
SIGINT	Signals Intelligence
SOC	Space Operations Center
StrC	Strike Coordinator
StrCont	Strike Controller
TBM	Theater Ballistic Missile
TCT	Time-Critical Target or Targeting
TEL	Transporter-Erector-Launcher
TMD	Theater Missile Defense
UCAV	Unmanned Combat Air Vehicle
USAF	United States Air Force

1. Introduction

In examining the ability of a new surveillance system or group of systems, it is usual to infer capability based solely on the characteristics of the sensors and platforms hosting those sensors. Important factors such as human decision making, data fusion, or communications are often assumed away, with the analysis focusing on the technical capabilities. In modern warfare, such an examination is only part of the picture, especially when we need to consider the utilisation and control of such a complex system within a time critical environment. As an illustration, Hura et al (2002) outlines the following future requirements needed to enhance the Command and Control (C2) of air operations with regard to Theater Missile Defence (TMD):

1. New sensors and sensor upgrades: Improved persistent sensors are needed with higher scanning rates for broad area search. Better tracking algorithms, High Range Resolution (HRR) capabilities for Ground Moving Target Indicator (GMTI), an all-source integration capability, better geo-location, and support for improved data link messages will contribute. More survivable platforms are needed to host these sensors.
2. Fighter sensor upgrades: Various software improvements may improve the capability for fighters to dynamically adapt to new threats. Weapon upgrades may also be required.
3. Dynamic Command and Control and Battle Management (C2BM) processes and tools: A variety of tools need to be developed. Some examples include decision aids and simple game theory techniques. Improved C2BM timelines should be developed via a combination of technical, organisational and cultural changes.
4. Collaborative environment and networked communications: A robust collaborative environment including automated tools, high data rate communications and data management tools, will help facilitating the development of an integrated air and ground picture.

In general, Hura et al (2002) outlines a number of issues that need to be addressed to ensure total system effectiveness. Sensor processing, evaluation, dissemination and re-tasking of multiple intelligence sources requires integrated tasking linked to guidance and objectives. Correlation and fusion across sensors require the integration of multi-source data to provide common operational and tactical pictures. Target development and nomination requires automation in line with the Air Tasking Order (ATO) and target lists. Weapon-target pairing and order issuance also require standardisation, automation, and linking of shooters to information from sensors. Fundamentally, tasks like TMD require a complex series of events, observations and decisions to work seamlessly. The ability to complete such tasks within a reasonable timeframe will require human interactions and capabilities beyond those provided by physical sensing and automated prosecution systems. Such capabilities are also required to prosecute Time-Critical Targets (TCT). The need for the efficient utilisation of Intelligence Surveillance and Reconnaissance (ISR) assets and integration with strike assets during these missions is especially high.

It is questionable whether the development of appropriate solutions as outlined above can occur without a thorough understanding of the processes to be undertaken, through detailed

Concept of Operations (CONOPS). The term CONOPS is often used in reference to an outline of possible platform or sensor use, without any actual description of the command relationships, interactions between the platforms, or human decisions that are required[1]. General CONOPS describing platform and sensor use may be valuable in the initial stages of an acquisition process, but are less useful when defining the specific characteristics of the system and its crewing structure. This is especially true for those platforms that will be carrying out C2 missions. The many difficulties that may arise in complex interactions between systems, operators, and the communications systems connecting the parts need to be fully understood to ensure successful employment in future operations. The aim of this report is to develop and describe an operationally relevant CONOPS for prosecuting TCTs and to examine the temporal and interactive limits those CONOPS imply.

1.1 CONOPS Requirements

We begin by outlining the scope of the CONOPS and the strategic assumptions that allow the CONOPS to be employed. At a basic level, CONOPS involve a goal, resources — sensors, platforms, weapons, information or even operators — and the processes that operate between them to achieve a desired outcome. At the tactical level, the CONOPS may involve only a simple process, such as an operator being given an image to analyse to determine its contents. However, for most operational level objectives, tasks will require synchronisation with other entities and operations. Communications between the entities are critical to executing the operation.

We will limit our CONOPS discussion to personnel and system components, and the organisation and interactions of those entities. These processes will include those involved in C2 of both strike and ISR systems and those associated with developing actionable information from sensor data. We concentrate our discussion on surveillance, analysis, assessment, planning and execution by target prosecution and Battle Damage Assessment (BDA) (Hura et al, 2000). Details of the airspace management, transport, security and logistics will not be considered, and only cursory consideration is given to long-term planning mechanisms, and the mission level operation of assets.

1.1.1 Strategic Guidance

We initially consider the strategic level guidance required to allow efficient execution of operational plans. For the operational phases to work effectively, a strategic framework is required prior to the detailed planning for those operations. Such a framework helps the operators best plan their operations to support the commander's guidance. Essential pieces of the strategic guidance include:

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[1] The emerging United States Air Force (USAF) terminology to describe operations at the tactical level is Concepts of Employment (CONEMP). Unfortunately, detailed CONEMPs for future surveillance and reconnaissance systems do not currently exist. While recognising this terminology, we employ the more traditional term CONOPS in this document.

- **Purpose**: an outline of what the operation is to achieve, including expected timeframe and expectations for threats during different phases of conflict: for example prior to the outbreak of hostilities, and during the conflict with and without air superiority.
- **Resources**: the platforms, sensors, communications, basing, and personnel dedicated to the operation. Intangible resources, such as information about an adversary collected prior to the conflict, may also be critical. To perform high priority tasks in a timely fashion, it may be necessary to dedicate resources to that task. It is up to the leadership to resolve resource conflicts and allocate resources to best achieve strategic objectives. We assume this step has already occurred.
- **Processes**: In an emerging conflict, the processes for the strategic and operational planning need to be tested and in place. Although much of this is defined at the highest levels in doctrine, ad hoc processes are often employed during contingency operations.[2] Processes are needed to describe how operations should be conducted and the responsibilities of various parties in conducting those operations. For example, the development of the ATO, and the subsequent conduct of the brief, execution, and debrief. Strategic guidance from senior leaders gives the basis under which each mission is conducted. From this information an ATO is produced, missions are planned, and mechanisms are developed to allow assets to be re-tasked during mission execution.
- **Authority**: in performing the operations there needs to be clear delineation of the command structure: who has responsibility for what decision, who is responsible for what actions, and who has authority to use the given resources. A Master Air Attack Plan (MAAP) and ATO for each mission will be finalised by the Mission Commander under direction from the Combined Air Operations Center (CAOC) under the command of the Joint Force Air Component Commander (JFACC). For example, the JFACC could delegate authority for TCT missions to a designated group with the MAAP and ATO assigning ISR assets and strikers.

The strategic requirements outlined above are idealistic and by nature ignore difficulties in implementation. For example, Intelligence Preparation of the Battlefield (IPB) is needed prior to the outbreak of hostilities in order to engage TCTs effectively. Developing geographic information about known adversary infrastructure, road systems, terrain analysis, and other information is part of this process. Correctly prepared during peacetime operations, IPB will help to limit search areas required to find an adversary's critical military assets. Thus a percentage of the intelligence exploitation analysts and all-source analysts must be dedicated to this problem during peacetime to make the most effective use of limited sensors during wartime.

1.1.2 CONOPS Contents

Often CONOPS for future systems are produced to give a broad picture of operational concepts as they relate to particular acquisition programs. As such, the contents tend to be at a high-level without details relating specific operational requirements. Such CONOPS may be

[2] Recently, the USAF has moved to standardise many of the CAOC processes involved in planning and executing operations. The effort, which treats the CAOC like any other weapon system, is called the Falconer AOC.

useful initially, but such a level of definition does not give any guidance as to how operations will be conducted or the resulting capabilities required from each of the systems and their personnel. At the other extreme, CONOPS for existing military systems tend to provide large amounts of detail that are specific to particular objectives. The structure of the CONOPS may be occluded by the details of a specific operation.

In this report, we aim to develop a CONOPS for future systems which incorporates many of the lower level details required to fully understand the demands on the crews associated with future systems. A number of general operations will be needed to find and engage TCTs, and our goal is to understand the range of steps needed to carry out these operations. We include the following within the CONOPS:

- **Operational Roles**: here we define the operators and the roles they will be undertaking. This also includes the hierarchy of command between operators.
- **Operational Tasking**: we define the actual tasks that will be performed by operators. This includes the operation, which operator performs the task, the amount of time each task will take, and the start and end states that result from each task. For example, classifying an object within an image will take a certain amount of time, the start state involves obtaining an image and the end state is the classification, or lack thereof, of the object in question.
- **Tasking Priorities**: describes the priority between different task types. If a single operator has to undertake a number of different tasks, the priorities will most likely be different, requiring one task to be completed before another.

The resulting CONOPS may then be used in studies to determine how well they meet the operational requirements.

1.2 Report Structure

Firstly, we develop CONOPS for TCTs, based on knowledge from local subject matter experts and experiences from recent conflicts, taking into account demands on personnel and systems. The CONOPS include expected interactions, lines of command, decision-making and data flow: areas where the existing literature on CONOPS gives little detail (§2).

We then use a concurrent, discrete-event simulation system to model the CONOPS to obtain further information on the timing restraints imposed by the task (§3). We do not model to the level of detail of passing actual imagery, but by passing workload information and providing reasonable times for completion. This will highlight the operational bottlenecks for resources and personnel, and the time constraints on mission execution. Whether these delays are due to technical reasons, human capability, decision-making, or simply due to the complexity of the problem under consideration will be highlighted. This in turn informs the demands for communication provision and integration of these assets.

Finally, we consider the crewing requirements for a Multi-Sensor Command and Control Aircraft (MC2A) based on the developed CONOPS (§4). This will highlight, for a single scenario and CONOPS, whether the crewing levels assumed with the aircraft are likely to meet the demands of the TCT tasking.

2. TCT CONOPS Definition

In this section, we outline a CONOPS for the task of finding, tracking and destroying TCTs. We define a command structure: creating nominal staff positions and the command hierarchy, thus giving an outline of the required interactions. To this we add task descriptions, including approximate operational timings. This is not a detailed human factors study outlining the tasking on crew, such as that developed by (Naikar, 2003), but rather it is included as a rough guide for modelling the temporal requirements of human tasking.

2.1 TCT Scenario

We consider a specific scenario to outline the strategic level requirements. The scenario will drive the needs for operational practice and hence form the capability structure required.

2.1.1 Strategic Purpose

> The enemy is planning on employing 500 Land Attack Cruise Missiles (LACM) or Theater Ballistic Missiles (TBM) with a range of up to 1000 kilometres. We assume these assets are launched by roughly 50 Transporter-Erector-Launchers (TEL) in the launch area. The missile launchers move at 50kph (approximately 30mph) along known roads and the teardown time post-launch is 5 minutes, hence requiring rapid response. Deception techniques including decoys will be employed, and red force defences will attempt to screen red activities, evade detection, and jam blue force sensors. The timeframe is 2020, with 24-hour operations over a 30-day period. The operations involve a set geographic area of consideration, with varying topology, vegetation and weather conditions. The area under surveillance may be further reduced in size by pre-conflict intelligence and cueing. We assume no blue forces are operating within the region, and hence there is no requirement to de-conflict with ground forces.

The objective is to identify the ISR capabilities needed to find, track, and engage an adversary's mobile missile force. This objective includes determining the location of missile launchers prior to or immediately after the launch of missiles, tracking the missile launchers when they move, and destroying the missile launchers. We limit our discussion to operations involving prosecution of in-theatre assets, and do not consider the requirements of a layered blue force defence (Hura et al, 2000).

2.1.2 Resources and Authority

> A CAOC is used to perform C2 of air assets and the Space Based Radar (SBR). A Distributed Common Ground Station (DCGS) handles processing, exploitation and reporting of sensor returns. The CAOC and DCGS, or subcomponents of these assets, could both be located near the theatre or in Continental US (CONUS). For example, the C2 of TCT missions could be delegated to an MC2A aircraft, with the CAOC providing a supporting role. Surveillance assets are assumed to be on station due to the escalation of tensions. For this task we initially assume the following availability 24-hours per day:

- 1 MC2A with a Multi-Platform Radar Technology Insertion Program (MP-RTIP) radar providing interleaved Synthetic Aperture Radar (SAR) imagery and GMTI with HRR capability.
- 3 Global Hawk (GH) orbits with scaled MP-RTIP radar providing interleaved SAR and GMTI with HRR capability, plus Electro-Optical Infra-red (EOIR) sensor suite for still images and video.
- 1 Low Earth Orbit (LEO) SBR constellation overhead 40-80% of time with SAR and GMTI.
- 1 Rivet Joint orbit or Signals Intelligence (SIGINT) capable Global Hawk.
- Up to 20 shooters — F-35, F-22, B-2 or an Unmanned Combat Air Vehicle (UCAV) — providing selected EOIR or SAR images.

There is a potential inefficiency associated with allocating resources solely for the TCT task, in that other pressing surveillance and reconnaissance needs may go unfulfilled. Given the scale of the tasks involved in a major conflict and given the increasing intelligence requirements, it may simply not be possible to have all these resources dedicated to this mission. However, the priority of TCT targets may outweigh the delay associated with other operations, if effective dynamic tasking cannot be achieved. Understanding these tradeoffs may require a change in operational practice, as not all priorities will get covered, but such planning up front may eliminate much of the confusion resulting from ad hoc tasking in the CAOC.

We assume under this scenario that the CAOC has the authority to find and prosecute TCTs. Further, we assume that the MC2A is the prime C2 asset in charge of TCT prosecution[3], requiring all time critical information, undertaking all decision-making, and tasking prosecution assets. The MC2A handover workload at the end of its time on station is assumed to be minimal. SBR and GH tasking is performed by the CAOC with direction from the MC2A[4]. The ability of the MC2A to fulfil operations may be limited by the number of available onboard analysts and the speed at which the analysts can perform tasking, even though many of these operations may be completed in parallel.

2.1.3 Study Limitations

At this point, it is worth noting that we are working with a number of general assumptions with respect to our investigations that influence the CONOPS development within this paper:

- **Physical Environment**: We do not explicitly consider the spatial nature of the problem. For example, missed detections through aircraft turns, satellite nadir holes, terrain blockage — especially at high grazing angles — and foliage obscuration are not

[3] JFACC ISR asset control is delegated to CAOC (USAF, 2002). The CAOC is responsible for operational planning and integration and we assume the TCT C2 decisions are delegated to the MC2A (USAF, 2003).

[4] Some documents we have seen show the MC2A tasking the SBR constellation directly. However, current operating practice is for the Space Operations Center (SOC) to control SBR tasking as part of the CAOC, as there may be multiple entities requesting SBR sensor time. We assume the MC2A will not process space-based sensor data.

considered: we simply assume sensors are available and not occluded thus providing coverage.

- **Communications**: We assume that all communications are instantaneous and fault free, with no restrictions from error correction, relays, and network load.
- **Sensor Accuracy**: We do not consider the specific capabilities of the sensors, partially as this is dependent on the geography and partially due to the inherent difficulties in estimating such probabilities of detection.
- **Classification Failure**: There is no expected false-classification or non-classification of objects, although these may be approximated in future by extending the classification time range, thus assuming this work is contiguous. This has the implication of meaning that there are no mechanisms built into the CONOPS that have been modelled for recovering from error states or problematic situations.
- **Automation**: We assume automation will simply speed the tasks to be completed, such as tracking, and allow the operators to handle more tasks per unit time. At this stage, we ignore biases that may be introduced by automation such as false-positive and false-negative classifications, a tracker's dynamic model, and cross fixing with other sensors and the subsequent fusion of potentially incorrect information. We assume rapid, automated pre-processing of sensor data without human intervention. We also ignore human fallibility, and the possibility that increased information may actually slow analysts.
- **Planning and Operator Loading**: We do not consider asset planning and the optimising of operator tasking, such as the allocation of detections to analysts depending on geographic region. We simply limit the number of tasks analysts can undertake, to give an indication of the limitations due to a single person's ability to handle concurrent tasks. There is no dynamic task distribution based on operator loading.

Our focus is on the type of task to be completed, the time that task takes, and, assuming that task is performed correctly, the subsequent phases of the operation. We also focus on the total operator numbers required and the time required for completing tasks. This gives us a snapshot of the system performance assuming perfect execution and sensor performance. Subsequently we identify operator workloads and the time needed to examine individual targets. Because of these generous assumptions in system performance, it is probably safe to assume that our results represent the "best case" performance of the overall system.

The sensor capabilities imply further assumptions and clarifications:

- We assume perfect information output from the sensors. In reality, the GMTI HRR capability will never be as good as that from the SAR imagery for target identification. Thus, we assume SAR imagery of vehicles will be assessed, even if they start moving again. Targeting based on GMTI HRR information by itself is unlikely for the near-term future.
- Geo-rectification of fixed targets from SAR imagery is currently a labour-intensive task that involves removing distortion from SAR imagery and then overlaying this on geo-located imagery to provide precision coordinates.

- We assume the GMTI is able to reacquire previously stopped vehicles and correctly associate those tracks with imagery of the stopped vehicles: hence we assume perfect tracking. Thus, a stationary vehicle that restarts movement is immediately tracked by the GMTI. Good GMTI HRR performance is an implicit assumption to enable tracking.
- An initial rush of GMTI detections would be expected when an asset arrives on station. As such it is arguable that in a work-up period a fair amount of tracking may be undertaken, prior to prosecution of red forces. We assume a worst-case scenario whereby any situational awareness gained by previous assets on station has been lost and needs to be recreated.
- At this stage, we ignore Human Intelligence (HUMINT), Measurement and Signals Intelligence (MASINT), SIGINT, Electronic Intelligence (ELINT) and IPB integration and change detection software to discover movement during GMTI coverage gaps. Imagery Intelligence (IMINT) such as EOIR may also be used for targeting and identification, although this sensor option is not considered within these CONOPS.

2.1.4 Networking Implications with the MC2A

Given this assumed scenario, we examine the possible networking involved to use the MC2A aircraft for the TCT role. Figure 1 gives an outline of the overall interactions between systems with the MC2A as the decision-making entity. The MC2A processes its own radar data. The DCGS collates all external ISR sources from directly controlled assets[5]. SBR and GH data are sent to the DCGS for processing and storage. We assume that raw SBR and GH returns need initial processing during the collection phase before being passed for analysis. The CAOC or DCGS will be a good source of reach-back analysis and information for the MC2A. Potential offloading of workload for TCTs to the DCGS will require robust communications to send data collected by the MC2A to the DCGS for analysis simultaneously. One would imagine the MC2A requesting specific archived information from a rear location, or requesting information from an expert at a rear location. The exchanged messages could consist of tasking, coordinates, or other processed text and images.

[5] Other implicit cueing sources include foliage penetrating radar, hyper-spectral imaging, unattended ground sensors, SIGINT, and MASINT.

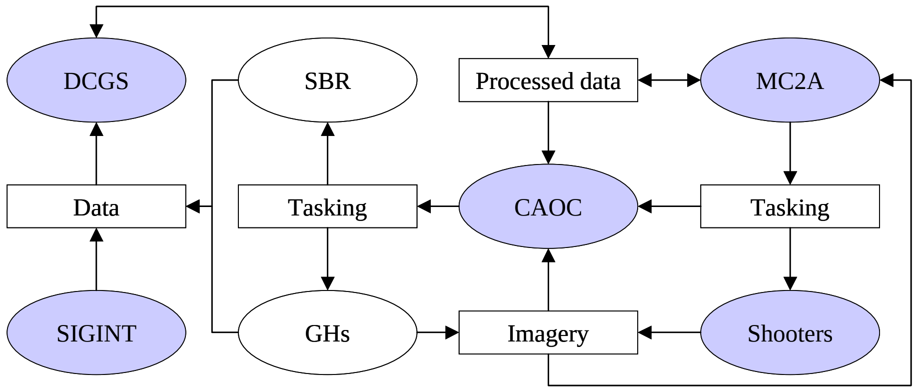

Figure 1: Component interactions to implement TCT CONOPS[6]

Given the specific sensors, we detail the projected communication interactions between platforms and ground stations or CAOC, ignoring communication limitations, characterising the type of data being sent: voice (simple text), processed data, and raw GMTI, SAR and EOIR data (see Table 1). The specific tasking at any one time could have a great impact on the amount of information transmitted, such as when radar alters mode from GMTI to SAR imaging.

Table 1: Communication interactions

		To						
		CAOC	**DCGS**	**MC2A**	**GH**	**SBR**	**Shooter**	**SIGINT**
From	**CAOC**	–	Voice, data	Voice, data	Control	Control	Voice	Voice
	DCGS	Voice, data	–	Voice, data	–	–	–	Voice
	MC2A	Voice, data	Voice, data	–	–	–	Voice, text	Voice
	GH	–	GMTI, SAR, EOIR	GMTI	–	–	–	–
	SBR	–	GMTI, SAR	GMTI	–	–	–	–
	Shooter	Voice	–	Voice, EOIR	–	–	–	Voice
	SIGINT	Voice	SIGINT	Voice	–	–	Voice	–

[6] Platforms and other force elements (states) are represented by ovals, with shaded ovals being manned. The rectangles indicate interactions (processes) with both one and two way communication shown.

2.2 TCT Concept of Operations

2.2.1 Operational Roles

In this section, the functional roles in prosecuting the TCT are defined. These roles are based on recent real-world operations, with extensions based on the greater ISR capability under our assumed scenario. The aim is to develop a command structure for TCTs that may be extended depending on the situation. This structure should be independent of the individual's location.

If such a structure were placed on an MC2A aircraft additional crew would be needed to perform flight operations, management, and self-protection. In a CAOC, liaison officers may also be required for de-confliction of other joint or coalition forces. Additional team members would be required to handle the integration of real-time SIGINT or other information. The crew structure defined below ignores many of these equally important supportive roles. The expectation here is for a large requirement on analysis and relatively few prosecuted targets. An outline of the TCT crew structure is given in Figure 2, and brief descriptions of positions are presented below:

- **Mission Commander (MC)** is in charge of the mission within the bounds of strategic guidance and external priorities. Pre-mission planning, control of re-tasking decisions and maintaining overall Situational Awareness (SA) of asset availability and other external factors are some of the mission commander's responsibilities. We assume the mission commander has the authority to prosecute attacks under the rules of engagement.
- **Mobile Target Coordinator (MTC)** is responsible for oversight of GMTI and SAR surveillance, including the maintenance of the overall surface picture, and the priority, no-strike and restricted lists. The MTC performs broad surveillance of moving targets using GMTI HRR, utilising effective clutter mitigation software and tracking capabilities (Keithley, 2002).
- **Analyst Coordinator (AC)** coordinates analyst requests for sensor activity, verifies identifications and BDA — hence de-allocation — after mission completion.
- **Analysts** perform the through-life tracking of each assigned potential target, including during the strike phase. Each analyst is able to track and analyse a limited number of targets.
- **ISR Coordinator (ISRC)** coordinates overall sensor allocation and usage, allocates tasks to sensor controllers and maintains awareness of sensor loading for GMTI, SAR and EOIR.
- **Sensor Controller (SenCont)** manages individual sensors, and information collation. The Sensor Controller implicitly performs specific radar tasking and scans for threats, such as cruise missiles, Surface to Air Missiles (SAM) and jammers.
- **Strike Coordinator (StrC)** is responsible for overall SA of strike execution including collateral damage estimates, direction of strike assets, and communicating imagery between analysts and strike assets.
- **Strike Controller (StrCont)** follows strike processes and provides information to strike platform. The strike process, including rules of engagement, is not considered in detail in our modelling.

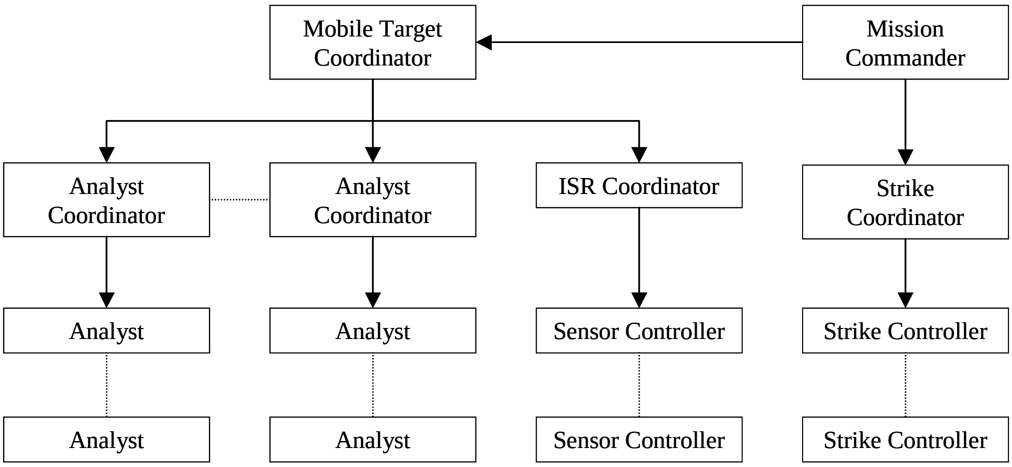

Figure 2: Staff structure for TCT

2.2.2 Operational Tasking

Given the roles above, we define a nominal tasking flow, with each task assumed to be independent. We follow the OODA loop (Observe, Orient, Decide, Act) construct while taking into account the levels of rough crew workload, and developing a tasking flow that is practical. The process presented here is based on those discussed in Vick (2001). Most of the operations would be conducted in parallel. For a sensor, we follow a process of tasking, access and collection, communication and processing, exploitation, analysis — including classification, identification and mensuration — and dissemination.

Table 2 summarises the tasking, including a description, the expected time range, the actors responsible for performing the tasks, and the beginning and end states. The given time ranges are estimated based on interviews with intelligence specialists, allowing us to give an indication of the overall delays that particular operations will face. We assume random uniform distributions for the task times. Analysts may maintain between 5 and 10 tasks for through life monitoring — a limit according to ability to maintain concurrent tasks — even though only one vehicle is worked on at a time. The geo-rectification process may be interrupted if the vehicle starts moving again: the sensor controller simply returns the tasking to the analyst for GMTI analysis. Further, the allocation of vehicles to analysts does take time, although it is expected that bulk allocations may be performed. Per vehicle, we expect allocation and de-allocation would be around one minute combined. Figure 3 outlines the flow between tasks.

Under this framework, it is possible to trace the process involved with examining a particular target vehicle. For example, consider a target that begins moving and is initially detected at 30 minutes into the mission, subsequently stops moving at 90 minutes into the mission, and then starts moving again within another 20 minutes. The first knowledge of this target occurs when it is detected by GMTI. The detection is selected by the AC allocated to the geographic area in question, and that detection is assigned to an analyst. Let us assume it takes 5 minutes to find an analyst able to examine the vehicle. If that analyst has five other vehicles to be examined,

that process could take 20 minutes, given a mixture of task difficulty, GMTI or SAR classification, and that no other targets are found during that time. GMTI classification for the moving vehicle would take another 4 minutes. A total of 29 minutes have thus elapsed from the discovery of the target to the recognition that it is a vehicle worthy of further attention. All of this assumes correct classification by the analyst, and no other form of cueing.

Table 2: TCT CONOPS tasks[7]

Task	Time	Actor	Begin State	End State
Allocate to Analyst	0	AC	Detected	Allocated
Classify moving from GMTI image	1-5	Analyst	Allocated	Classified, non-target
Classify stationary from SAR image	5-20	Analyst		
Request SAR (when GMTI lost)	1	Analyst	Allocated or Verified (for SAR classification or geo-rectification)	
Perform 1 ft spot SAR[8]	3-4	SenCont		
Verify target classification	2-5	AC	Classified	Verified
Mensuration of moving target GMTI	2-5	Analyst	Verified	Mensurated
Geo-rectification of stationary target SAR	5-10	Analyst		
Report target, check details	1-2	AC	Mensurated	Reported
Decide to prosecute target	5-10	MTC	Reported	Attack
Target prosecution including collateral damage estimation and strike control	5-15	StrCont	Attack	Destroyed
Request EOIR	1	Analyst	Destroyed	
Perform EOIR	3-4	SenCont		
BDA using EOIR	5-15	Analyst	Destroyed	BDAd
De-allocate detection	1	AC	Non-target, BDAd	NA

Continuing the example, the prosecution process would require verification taking another 2 minutes, GMTI mensuration identifying the rough target location taking 3 minutes, reporting taking 2 minutes, and a decision of 8 minutes. This total process takes 15 minutes, assuming no delays, prior to the strike process. The vehicle only stops moving 60 minutes after being detected, hence geo-rectification from SAR imagery would not be required. The strike process would take, for example, 10 minutes, giving a total time from detection to strike of 54 minutes.

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[7] The roles of the MC, ISRC and StrC are not detailed within the tasking described above, due to the limited interaction between external entities and limitations on the optimal allocation of tasks.

[8] We assume SAR imagery includes motion compensation, range and data compression prior to transmission, with image formation via azimuth compression of phase history after transmission.

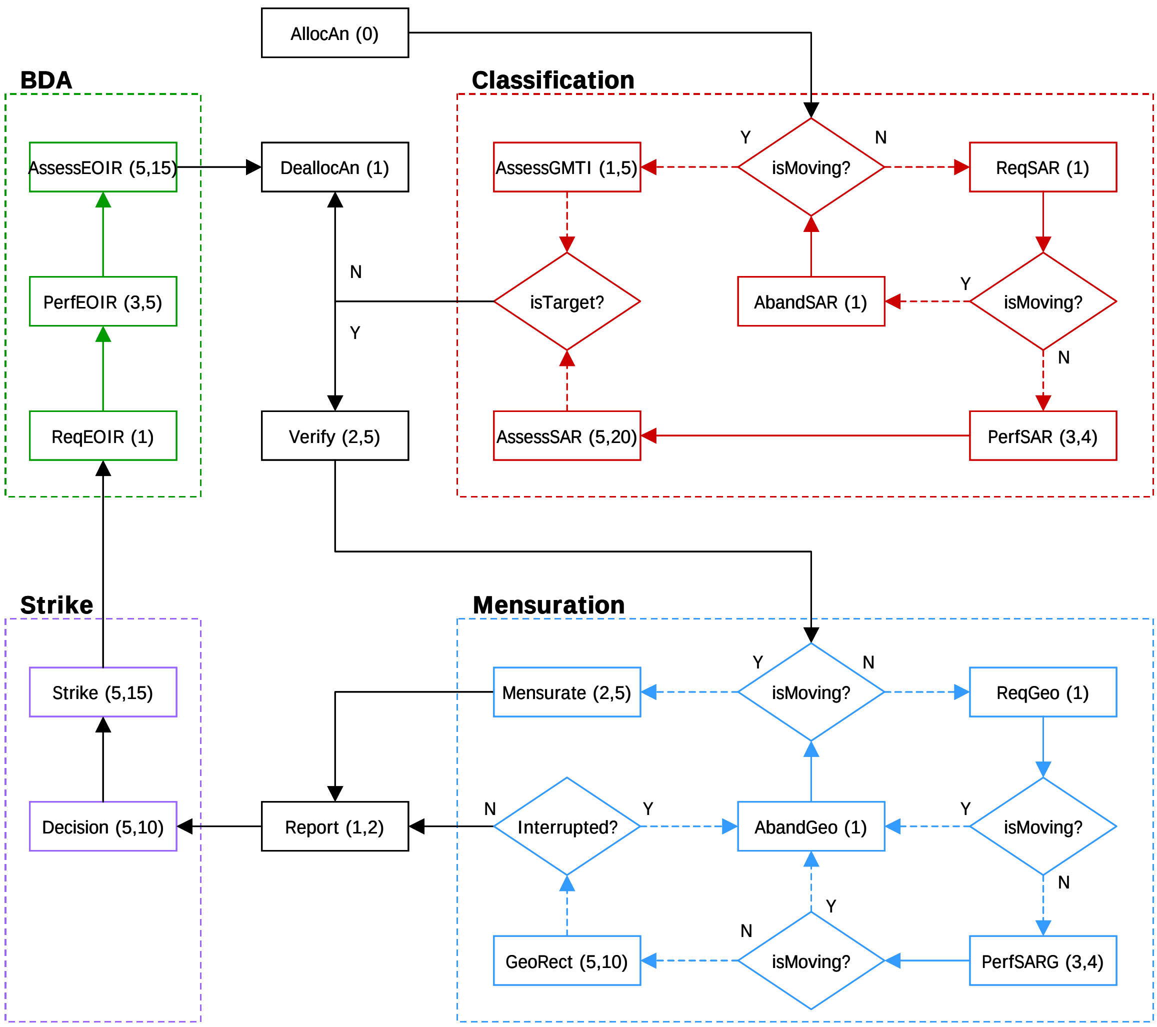

Figure 3: CONOPS flow of tasking

2.2.3 Tasking Priorities

The following are the task lists for each actor with multiple tasks in increasing priority order:

- Analyst Coordinator: Allocate Analyst, De-allocate Analyst, Verify, Report.
- Analyst: Request EOIR imagery, Assess EOIR imagery, Assess GMTI, Request SAR imagery, Assess SAR imagery, Mensurate location using GMTI data, Request SAR for geo-rectification, perform geo-rectification.
- Sensor Operator: Perform EOIR, Perform SAR, Perform SAR for geo-rectification.

Each task is placed into a queue, so that the oldest tasks of each type are performed first, starting with the highest priority tasks. From this information, it is possible to unambiguously decide the order of operations. Differences in performance will thus be influenced by the interaction between crew. In reality, task priority will depend on specific details; however, for our purposes this ordering will suffice.

As can be seen, there are a large number of variables given the potential range of times needed for the various tasks. Further delays due to other tasks increase the complexity of estimation depending on the size of the crew, the number of vehicles, and the rate of range in movement. The next section examines the simulation of the CONOPS to allow us to determine the influences of such interactions.

3. TCT CONOPS Dynamics

Given the CONOPS described above, the imperative questions relate to how these CONOPS perform in a dynamic and asynchronous environment. It is possible to get a sense of the information requirements and static operator load simply from the CONOPS description, and this in turn will inform the overall delay in engaging a TCT. However, the CONOPS describes an inherently concurrent, dynamic and interacting system. A prime example of this is operator loading: analysts may work on differing tasks and on average be able to cope with the loading. In peak times, however, the limited number of analysts will affect the ability to perform all tasks in a timely fashion. This section examines the dynamic modelling of the developed CONOPS, to test their tolerance and robustness in completing the task as required, assuming that we maintain the same overall CONOPS structure. The aim is to see whether the dynamics of the concurrent system affect performance, both in terms of the time from detection to prosecution and in terms of the operator workload.

To determine answers to these questions, we need to model the process described by the CONOPS, to determine the delays involved in finding and engaging TCTs. The simulation does not have to pass imagery for example, but can simply pass task information such as expected times for completion. To do this we have implemented the CONOPS in a Coloured Petri Net (CPN) system (Jensen, 1997), which allows the modelling of timed discrete event, concurrent, asynchronous systems. This produces a Monte Carlo model, allowing the temporal modelling of the CONOPS application. Specifically, we implement a Common Operating Picture (COP) that contains all sensor detections, thus representing the environment and sensor assumptions, and we have a set of crew specific tasks. We model the processes undertaken by the crew as they classify, decide and prosecute the sensor tracks, with process times modelled by randomising the delays within the given bounds.

We examine the results in terms of the overall time to complete the simulation, the average time taken to analyse each of the vehicles, the average load on each of the different types of operators, the amount of time spent by vehicles awaiting action by the loaded operators, and the proportion of both GMTI and SAR sensor usage including the number of interrupted processes. The results presented here are the averages of twenty randomly seeded trials. This gives us an understanding of the trends likely to develop in such scenarios, allowing broad differences between results to be easily discernable.

3.1 Base Case Analysis

We examine the base scenario when a number of vehicles are introduced over a 3-hour tasking window. The simulation time following the 3-hour period represents the time required to clear the backlog of tasks. The 3-hour timeframe will avoid the need to consider crew rotations due to operator fatigue in a high-stress environment. The following assumptions are made:

- **Crew structure**: we start with one Mobile Target Coordinator (MTC), three Analyst Coordinators (AC), three groups of five Analysts, three Sensor Controllers and three Strike Controllers. This amounts to 25 crew members, without the implicitly modelled

Mission Commander, Strike Coordinator and ISR Coordinator, plus other supporting crew members such as pilot, co-pilot, navigator, communications, and so on.

- **Vehicle set**: 300 vehicles are considered as a simplification of the stated scenario, 5% of which are targets. 60% of the vehicles are moving and detected by GMTI in the first minute, and 40% start moving over the remaining simulation time[9]. Every vehicle either starts or stops moving on average once an hour. Therefore we have 180 vehicles (9 targets) appearing immediately and 120 (6 targets) over the remaining time, resulting in an average of two targets every three minutes.

The assumption is made in the scenario that there will be an initial surge of vehicle introductions as GMTI surveillance commences. It takes some non-trivial amount of time to gain SA after getting on station, regardless of the effectiveness of the handover from previous aircraft. If the analysis is conducted from a CAOC with an ongoing analysis environment, there will still be an initial rush with the introduction of new material[10]. For example, a GH arriving within theatre would introduce new detections for analysis or for fusion.

3.1.1 CONOPS Timings

We firstly examine the time taken using the CONOPS to analyse each target, both to run through the complete CONOPS, and to examine the kill-chain sequence. We define the kill-chain as the time from first detection of the vehicle until either classification as a non-target vehicle or until the completion of the strike process, giving a measure of the urgent tasking while attempting to detect TCTs. The priority of operations is influenced by their relative place in the kill-chain. So, for example, performing BDA EOIR analysis is a low priority for analysts when there are unclassified vehicles[11]. Likewise, de-allocation of non-targets or prosecuted targets is a lower priority for analyst coordinators if other verification or reporting duties require attention, as stipulated by the CONOPS. Table 3 gives a breakdown of the CONOPS times required for the kill-chain analysis and complete analysis per vehicle. This is separated by targets and non-targets as the kill-chains are of differing lengths, and we also isolate the component time of the total time where a vehicle is awaiting analysis.

The overall time required for analysis of non-targets is 26 minutes per vehicle, as this involves only classification and de-allocation. The total kill-chain time is slightly shorter as we do not include the lower priority de-allocation of vehicles to analysts: 24 minutes. What is noticeable is the non-target time waiting for analyst processing: the kill-chain wait is 19 minutes with the classification analysis being just over 5 minutes, reflecting the combination of GMTI and SAR methods. Thus the wait-time implied by the crew loading is nearly four times the time it takes for classification analysis. We would expect that the overloading of operators would be similar for targets, with on average 20 minutes per target from detection to operator action.

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[9] In reality the number of vehicles appearing would be dependent on the rate of movement.

[10] The size of this initial surge may be modified with differing classification capabilities, levels of IPB, or vehicle rates of movement.

[11] We assume the BDA is of low priority in following with the assumption of correctness in classification and mensuration, as the assumption is that the strike is successful.

This is of course dependent on the previously stated assumptions: time for classification, number of operators, the appearance rate of vehicles, and so on.

Table 3: Target and non-target processing times (minutes) for kill-chain and complete CONOPS

Vehicles		**Kill-Chain**	**Complete**
Non-Target (285)	Wait Prior	19.0	19.9
	Analysis	5.3	6.3
	Total	24.3	26.2
Target (15)	Wait Prior	37.6	56.1
	Analysis	36.9	52.8
	Total	74.5	108.9

For targets it takes 109 minutes to complete the prosecution of the chain, with the kill-chain component taking 75 minutes. The average kill-chain wait-time for the targets is 38 minutes, in addition to the 37 minutes on average for analysis: more than half of the kill chain time is spent waiting for operator action. The immediate implication is that, given the current vehicle numbers, vehicle arrival rate and crewing levels, and without improving the speed of the different methodologies, the staffing levels would need to be increased if we wished to prosecute TCTs in under an hour. The inherent problem being we cannot distinguish between targets and non-targets until after the classification is completed, thus we cannot rank potential targets for priority work.

The total kill-chain workload is 6 to 1 weighted towards non-target vehicles, given the 19 to 1 total numbers. Although the processing time per vehicle is substantially less, the large classification load has a huge impact in kill-chain operations: about 25 hours of time spread between 15 analysts and the sensor operators where required for SAR imaging. For targets the kill-chain processing time results in over 9 hours being spent by analysts, decision makers, and sensor and strike coordinators. The obvious implication is that the greatest benefit to such operations would be from a quicker initial classification.

3.1.2 Operator Workload and Bottlenecks

We now examine the operator loading normalised to give a number of minutes per operator role, both on kill-chain tasks and the overall classification process (see Table 4). This also indicates the total simulation time. We then examine in the same manner the operator wait-times (see Table 5), including the wait from detection to initial operator action[12]. The overall simulation time is an average 65-minute extension to the time required for the introduction of

[12]As stated earlier we assume that each analyst may reasonably cope with between 5 and 10 vehicles at any one time, representing the need and ability of people to consider a number of simultaneous targets even though analysis may concentrate on particular entities from time to time. Limiting the number of vehicles that may be allocated to analysts at any one time also implicitly implements a crude work-sharing algorithm in the simulation, by limiting potentially high random workload allocations. We made the assumption that the allocation of vehicles to analysts would take minimal time as this would involve block allocation of potential targets, most likely grouped by geographical location, and the first bottleneck would be more at the analysis phase.

targets (180 minutes). This additional time is not unreasonable given the time required to process those last appearing targets. For example, over the last ten minutes 6 to 7 vehicles would appear, with the possibility that 1 in 20 may be targets. Thus any mission with a large number of developing targets will require substantial work, if all those vehicles require action prior to a handover of tasking[13].

Table 4: Normalised operator loading (minutes) for kill-chain and complete CONOPS

Operator	Kill-Chain	Complete
Total simulation time		244.9
Analyst	100.6	111.4
Analyst Coordinator	25.3	125.3
Sensor Controller	66.8	87.0
Strike Controller	49.2	49.2
Mobile Target Coordinator	113.7	113.7

We can generally assume that the average load on the operators is not excessive considering the 245-minute overall tasking, but this does not give us an indication of the loading at any particular time, such as when the initial 180 targets appear. The largest kill-chain work requirement is on the Analyst and the MTC (see Table 4). The AC also has a high overall workload: the majority of this is the lower priority management of the distribution of vehicles to the analysts. This work is important, but in this context we assume that the analysts already have a reasonable workload given the ability of ACs to provide an initial group allocation of potential targets to Analysts.

Table 5 details the amount of time that vehicles are waiting for each class of operator. The high wait-time attributed to the Analysts is immediately evident. This is not unexpected as the Analysts undertake the first substantial kill-chain processing once a target has been identified. The pre-analyst allocation wait refers to the wait times attributed to the loading of analysts to their capability limit, as mentioned above, even though this is technically waiting for the ACs to perform the allocation. Combining these two figures we see that all detections spend a total of 374 minutes per analyst waiting for activity. The measure is somewhat misleading in that this time may include the concurrent timings of several detections, but it gives an indication of the overloading of operators not evident from the operator loadings. The results from Table 5 also indicate that ACs are able to readily cope with their kill-chain workload, as are the Strike Controllers. There are, however, significant waiting periods for both the MTC and Sensor Controllers. The MTC, for example, is the entity deciding whether to strike an identified target, and this is their only kill-chain task. On average for the 15 targets, there is a wait-time of nearly 8 minutes for each classified, verified and mensurated target prior to the MTC

[13] It may be possible in these experiments for a single analyst to have a few vehicles to investigate at the end of the on-station period while others have no work to do, simply as there is no work-sharing between operators implemented in the simulation.

making a decision to strike. This is simply due to the overlap of decisions in a dynamic scenario.

Table 5: Normalised operator wait-times (minutes) for kill-chain and complete CONOPS

Operator	**Kill-Chain**	**Complete**
Pre-Analyst Allocation (AC)	50.4	50.4
Analyst	323.7	338.2
Analyst Coordinator	3.0	93.5
Sensor Controller	78.8	94.1
Strike Controller	4.4	4.4
Mobile Target Coordinator	116.8	116.8

3.1.3 Proportion of Sensor Use

We now consider the proportion of sensor use: either GMTI HRR for moving vehicles or SAR imagery for stationary vehicles (see Table 6). 83 percent of classifications are GMTI HRR, with over 16 percent being performed by SAR imaging. The high rate of GMTI HRR classification is expected due to the speed of the imagery collection and because the initial identification of vehicles is performed by using GMTI HRR. SAR classification analysis does take significantly longer to perform than the GMTI analysis, but this does not influence the proportions greatly as we can classify from the SAR imagery once it is obtained, regardless of whether the vehicle begins movement during the classification process[14]. The proportion of GMTI usage does decrease in the mensuration phase of the operation. Vehicles are initially detected by the GMTI, and they stop moving on average an hour after that initial detection. As we have seen, the classification process will take around 24 minutes, followed by the verification (3.5 minutes), and the delays prior to verification (minimal time) and prior to commencing mensuration (3-5 minutes). Thus after approximately 30 minutes, this being the time taken before mensuration is commenced, there is an increased chance that the vehicles may have stopped moving. This in turn would increase the likelihood of employing SAR geo-rectification for mensuration. Overall the proportions are influenced by the phase of analysis along the kill-chain, as we always begin from a moving vehicle.

Table 6: Percentage of sensor usage

Event	**GMTI**	**SAR**
Classification (300 vehicles)	83.3	16.7
Mensuration/geo-rectification (15 targets)	69.7	30.3

[14] We do not allow SAR imaging to be interrupted due to the short time scale. We do not take into account the chance that the imaging is not successful due to the vehicle starting moving during imaging. We only account for the vehicle starting to move prior to imaging.

We also consider the failure rate of SAR processes, either those that are not commenced or interruptions to geo-rectification (see Table 7). During classification a reasonable proportion of the potential SAR classifications were abandoned prior to the SAR imaging taking place: nearly 9 percent. This means that during the intervening time between the request for SAR imagery and the actual performing of that imaging there is a change in the movement of the vehicle under consideration. Overloading of the sensor operator could result in the abandonment of the SAR imagery process and thus increase the classification time[15]. Movement may also occur during the geo-rectification process. The proportion of completed SAR requests during the mensuration phase — only 3 percent abandoned — is most likely due to the higher priority accorded to this tasking. Nevertheless the subsequent analysis is abandoned in 9 percent of those cases prior to any analysis, with geo-rectification being abandoned in over 14 percent of the cases attempted. In total this amounts to over 26 percent of all geo-rectification attempts failing, simply due to the vehicle commencing movement during the process. The higher proportion of failure during mensuration over classification may be initially explained by the greater chance of failure during the mensuration processes.

Table 7: Proportion of SAR requests abandoned or geo-rectification interrupted

Event	Percentage
Classification SAR requests abandoned prior to SAR	8.9
Geo-rectification SAR requests abandoned prior to SAR	3.2
Geo-rectification abandoned prior to analysis	8.9
Geo-rectification interrupted	14.5
Combined geo-rectification failure	26.6

3.1.4 Discussion

From the simple descriptions above we can identify a number of salient points. Given the assumptions about classification, the wait-time for vehicles spent waiting for classification is of major concern. Speeding the initial classification process is likely to give the biggest performance boost, whether this is by improving the process or increasing the number of analysts. The Analysts are identified as having the highest workload and associated wait-time, with a concern that the MTC's decision making may be holding up the strike process when a rush of targets appears. Finally we get a sense of the proportion of sensor usage, and an indication that the stages of the kill-chain analysis may influence the requirements for sensor employment.

The base case is very stylised in nature, and may identify issues that are not of concern when examined in greater detail. Nevertheless, the results above give us a baseline for comparison when modifying scenario characteristics. We have an understanding of the likely kill-chain timings, the operator loadings and bottlenecks and the expected proportion of sensor use and SAR failure. In the following sections we move to a graphical presentation of results to

[15] We do not consider the abandonment of the request without notification from the Sensor Controller that the imagery cannot be collected. Instead we assume the analyst concerned will continue with other work while waiting for the imagery to appear for SAR classification.

highlight these comparisons, and we concentrate on the information available from the kill-chain, as this is of greatest interest in a TCT scenario. Complete tabular results may be found in section B.

3.2 Changes in Decision Making Speed

We begin our studies into the effects of environmental changes on CONOPS performance by changing the time required by the MTC to make a decision to strike a target, altering the base case (5-10 minutes) to examine an increased decision-making time (10-15 minutes) and also a decreased decision-making time (1-5 minutes). Considering the chain of events, the expectation would be that these changes would simply speed up the process of striking the targets.

Figure 4 shows the changes in the kill-chain times stemming from the change in decision time, and as expected there is no significant change in the processing of non-target entities. We also get a minimal decrease in the execution time for the target kill-chain due to the change in decision making time. There is, however, a significant difference in the target wait-time, which is much greater than would be accounted for simply by the decrease in execution. The implication is that the reduction of decision-making time greatly reduces the chances of MTC overloading. Figure 5 shows how the total simulation time drops slightly, and how the only change in workload is attributed to the MTC. Figure 6, however, shows how dramatically the wait-time may change: the MTC wait-time is substantially reduced compared to the linear reduction on the decision time. There are negligible differences in the proportion of sensor use, as would be expected given the lack of change in sensor chain performance. This experiment shows an isolated case of where a linear decrease in time taken to complete a task can lead to a greater decrease in the wait-time attributed to an analyst.

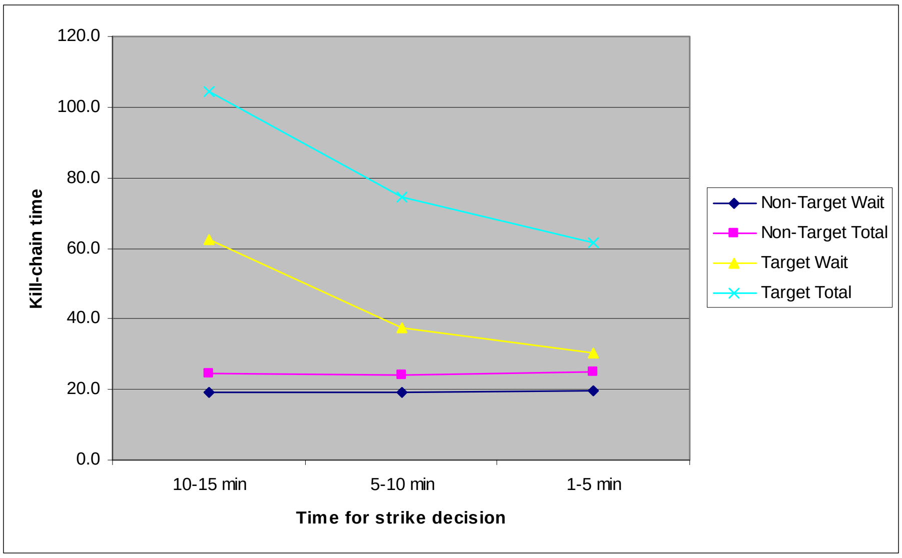

Figure 4: Kill-chain times per vehicle with decreasing decision time

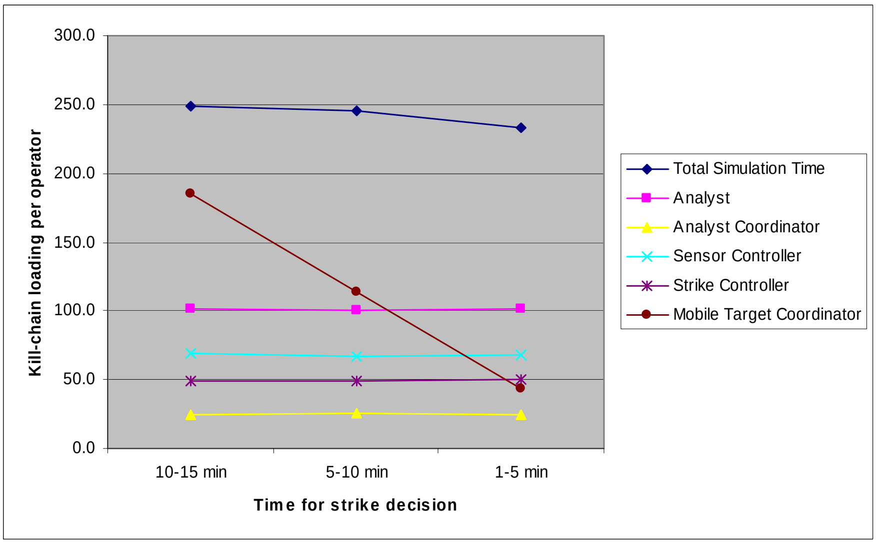

Figure 5: Operator loading with decreasing decision time

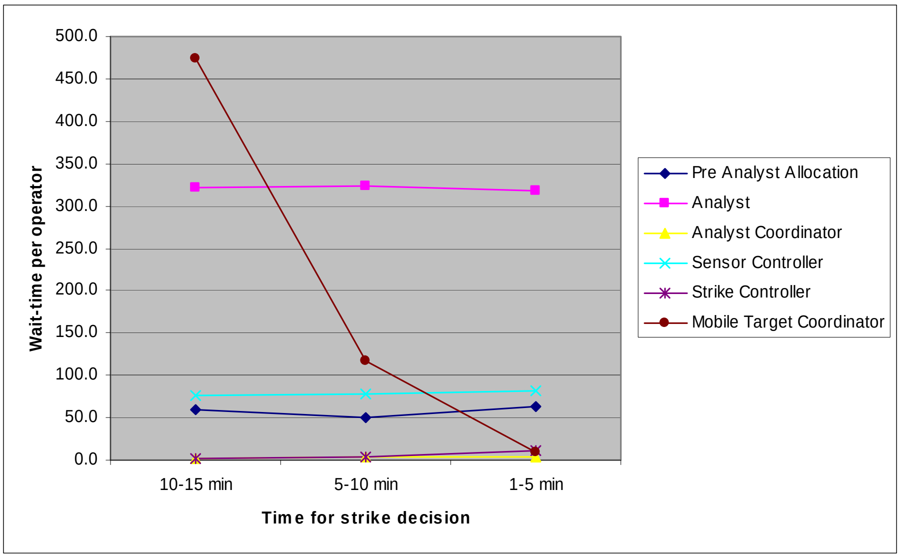

Figure 6: Wait-time per operator with decreasing decision time

3.3 Changes in GMTI Classification Performance

One important issue, beyond the capability to correctly classify vehicles as targets or not, is whether automation makes certain tasks manageable within a certain time frame, or at least feasible to complete. Beyond the standard requirements for processing GMTI and SAR imagery, there are likely to be a number of tools made to assist in the identification process. For example Automatic Target Recognition (ATR) software, SAR change-detection software, and GMTI data reduction will result in faster processing as well as introducing biases to the classification process. We list a number of forms of automation that would be useful for TCT:

- GMTI classification: ATR for HRR information, ATR based on target behaviour, data fusion tools to use non-GMTI information to aid in classification
- SAR classification: ATR algorithms, automated cueing for analyst interpretation, data fusion
- SAR execution and tasking: automated tasking and prioritisation tools, cross-cueing tools
- SAR and EO geo-rectification: automated "RAINDROP" tool to align reference imagery to SAR imagery, linked with rapid point mensuration for 3D targeting solutions
- Strike: Geo-location tools linked with ISR tasking and targeting tools, and then to strike
- BDA: automated ISR tasking tools, prioritisation tools or decision-making tools to de-conflict ISR needed for BDA and for next ATO cycle
- SIGINT: automated cross-cueing of SAR/EO based on SIGINT, and ATR for targeting

As can be seen there is great potential to speed classification, but also potential to hinder rapid analysis. To consider the issue of classification speed in more detail we examine the effect of modifying the time range for GMTI classification alone. This will give an indication of the sensitivity of the CONOPS to improvements in the general classification process over the specific target prosecution process. Note that the means of the GMTI timings—5-10 minutes, 1-5 minutes and 1-2 minutes—are not linear.

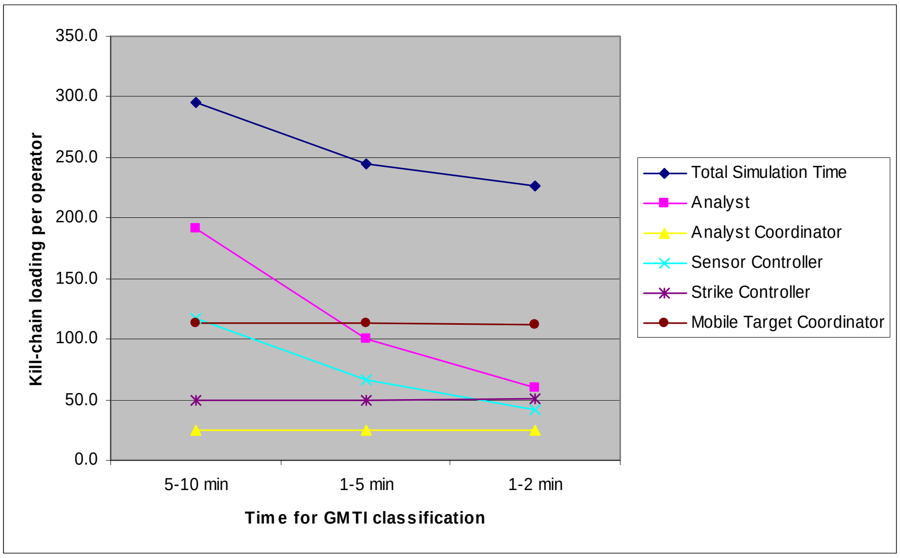

Figure 7: Operator loading with decreasing time for GMTI classification

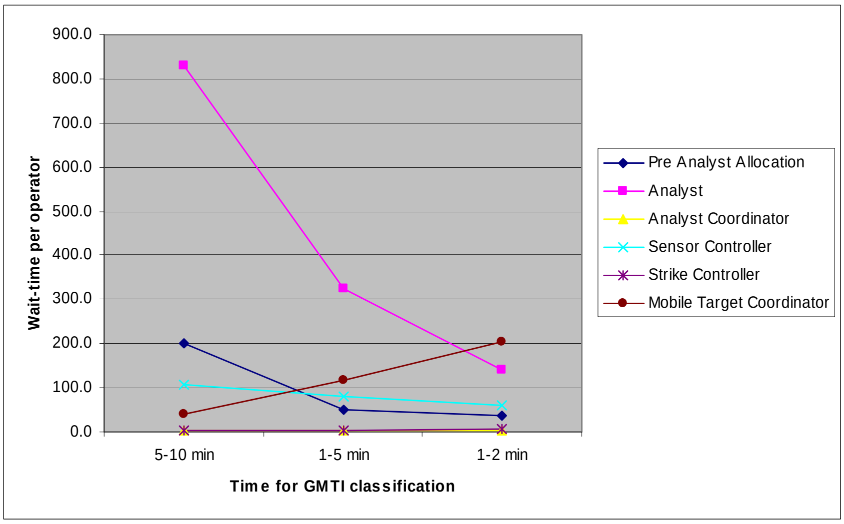

Figure 8: Wait-time per operator with decreasing time for GMTI classification

As expected we get a drop in the kill-chain times for both targets and non-targets, and we get a reduction in the overall execution time as shown in Figure 7. We get a workload decrease for Analysts with the decrease in GMTI classification time, and the Sensor Controllers' workloads decrease due to a secondary effect of a reduced requirement for SAR classification. When considering the vehicle wait-times (see Figure 8) the decreased loading on the sensor controllers and particularly the analysts are obvious. The flow on effect is not so obvious: the MTC wait-times are increasing as the potential prosecutions are delivered for decision more rapidly. This illustrates how changes in operator practice may easily influence the workload of other crew members, through the flow on of requirements.

3.4 Changes to Vehicle Numbers

The next experiment considers an increase in the number of vehicles being analysed from 100 to 300 to 500. During these tests we maintain the same crew composition, the same non-target-target mix (95%-5%), and the same proportion of vehicles detected by GMTI immediately to those visible on an ongoing basis (60%-40%). The increase in the number of vehicles represents either an increase in the density of detections or an increase in the area covered by the surveillance, given the lack of spatial representation.

Looking at the average kill-chain times as the number of vehicles increases we do get an increase in overall processing times: the analysis times are the same, but the wait-time spent per vehicle grows roughly linearly. The overall time to complete the tasking increases linearly as well, and in examining the loading on operators (see Figure 9) we see a roughly linear increase in workload for all operators. The exception is the Sensor Controllers with a greater than linear increase in workload, due to the greater chance that SAR imagery and analysis will be required (see Figure 11), as identified in the previous section. What is notable is the greater than linear increase in wait time for the Analysts, including pre-analyst allocation, and Sensor Controllers (see Figure 10).

The implication of these results is that even though the workload of an individual may only increase by a small amount, the resulting delay in attempting analysis on a particular vehicle may be much greater than expected. There are further implications towards the communication network load stemming from these results. The indications are that with larger numbers of vehicles, given the other assumptions, approximately 25% of classification and mensuration work is being performed by SAR analysis, even though GMTI provides a substantial advantage. Given the larger information requirements for such imagery, there may be a higher loading on networks once the potential target numbers increase.

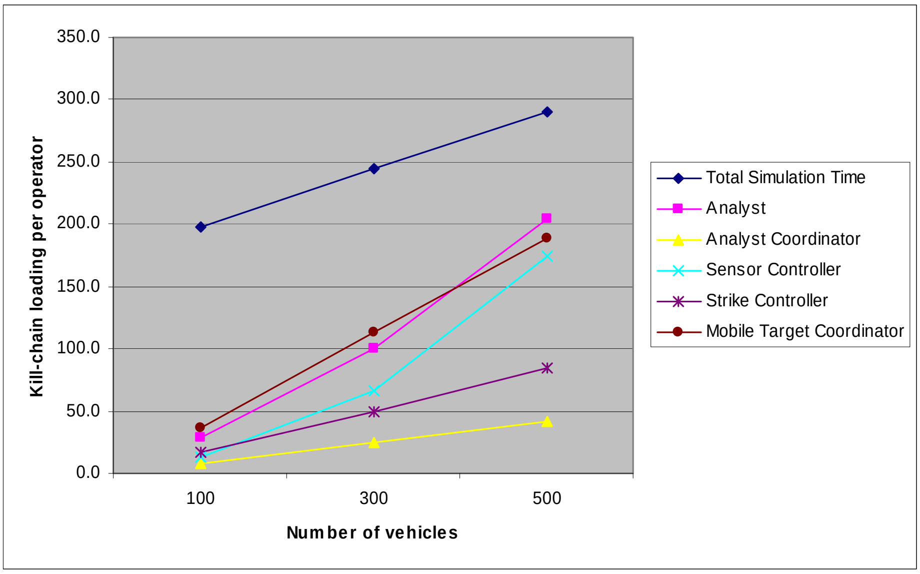

Figure 9: Average kill-chain loading per operator with increasing vehicle numbers

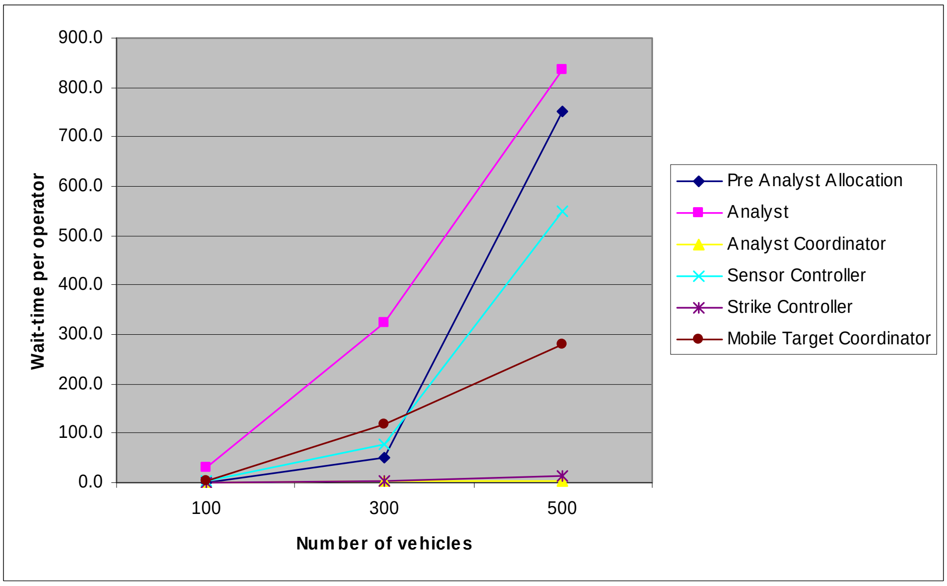

Figure 10: Kill-chain wait-time per operator with increasing vehicle numbers

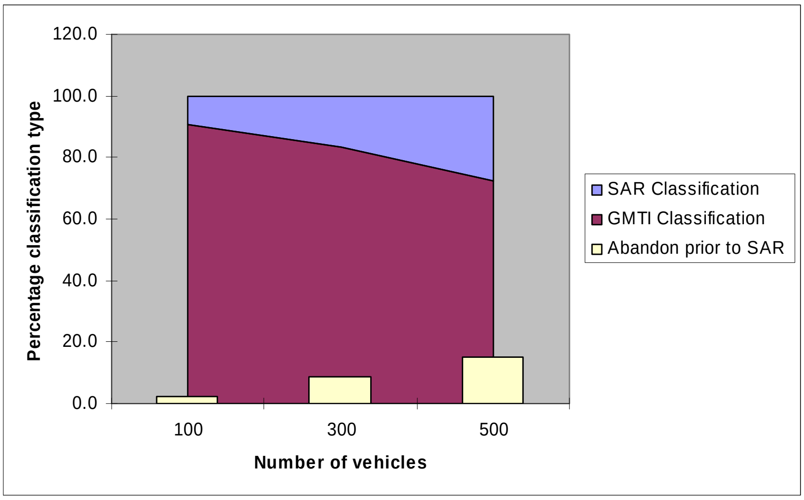

Figure 11: Proportion of classification methods with increasing vehicle numbers

3.5 Changes to Vehicle Movement Rate

As the choice of whether to use SAR imaging or GMTI classification is dependent on whether the vehicle is stationary or moving, for our final experiment we look to determine whether rates of change in movement alter the ability to classify targets. To do this we examine a fixed number of vehicles and alter the movement rate of those vehicles to examine the effect on sensor usage.

Figure 12 shows roughly the same workload for most operators, with a reduction in effort required from the Analysts and Sensor Controllers commensurate with the overall reduction in SAR usage for classification[16], as can be seen from Figure 14. The reduction in SAR usage is also accompanied with a reduction in the rate of abandonment. Figure 13 also demonstrates the reduction in the need for SAR classification by the lowering of the wait-times for both Sensor Controllers and Analysts. The obvious implication is that the rate of movement change, and hence switching between sensor types, can greatly affect the workload of operators and likewise affect the network loading given the disparity between network loading caused by GMTI and SAR imagery.

[16] The last change is from one hour to two hours, and is not linear with the previous 15-minute changes.

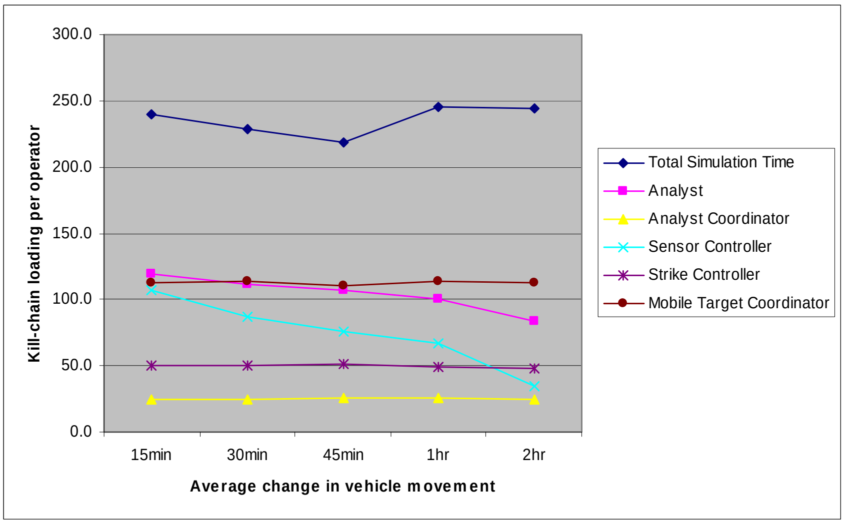

Figure 12: Operator loadings with decreasing rate of vehicle movement

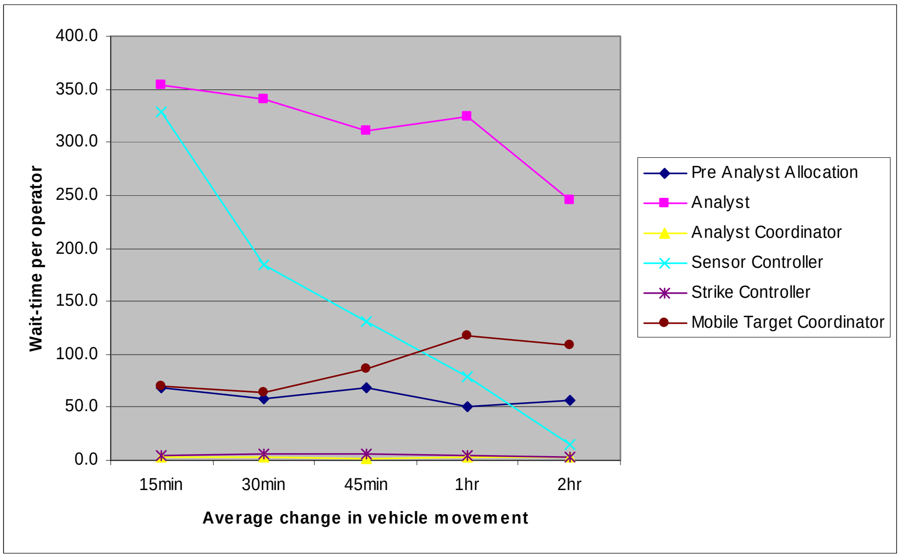

Figure 13: Operator wait-times with decreasing rate of vehicle movement

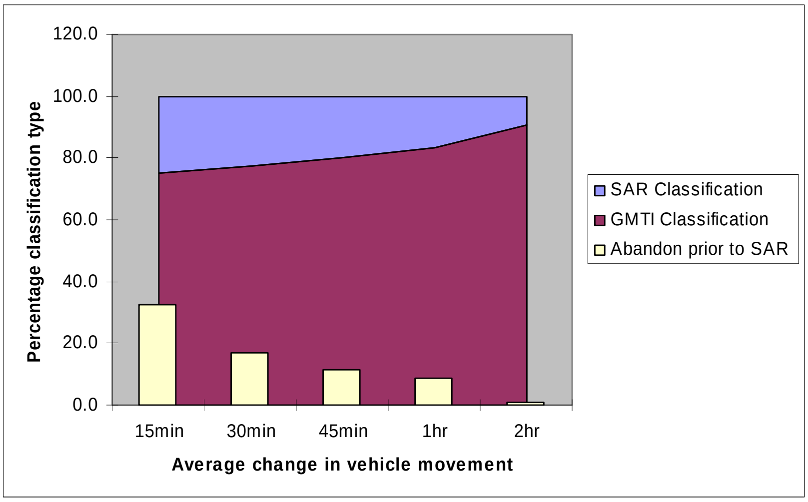

Figure 14: Proportion of classification methods with decreasing rates of vehicle movement

3.6 Summary

In this section we have performed a number of experiments designed to test the dynamic interactions within the defined CONOPS. The baseline analysis indicates the importance of rapid initial classification of vehicles to determine whether they are targets for prosecution. Altering our CONOPS with a potentially rapid first-pass classification, adding additional analysts, or assisting the introduction of technology to speed classification would have the greatest impact in speeding the overall process. This initial experiment also gives us an indication of the proportion of sensor use given the scenario assumptions.

After providing a baseline for comparison we have examined the effect of modifying the CONOPS timings: both classification speed and decision-making speed. Reducing the time of decision-making reduces the overall scenario length but also leads to a greater than expected reduction in the time spent by targets waiting for the decision process to begin. This also highlights the need to take into account the wait-time rather than just simply the workload levels in deciding the level of crewing.

Reducing the time taken to perform GMTI classification reduces the overall simulation time and the workload on analysts, and significantly reduces the time vehicles spend waiting for analyst action. Further flow-on effects result in a decrease in the amount of SAR imagery required and hence a reduction in the workload of the Sensor Controllers. The speeding up of classification also flows on to the MTC: increasing the wait-time for targets without affecting the overall MTC workload, simply because targets are identified faster. This again identifies wait-times as being critical in reducing overall classification times. Although in this experiment the overall kill-chain time is reduced with the classification speed, this reduction masks the further delay from the MTC bottleneck.

Further experiments have examined changing the external environment: changing vehicle numbers, and changing their movement rate. With a linear increase in the number of vehicles the wait-time on analysts increases drastically, with the flow-on effect of increasing the need

for SAR classification. This may result in a greater than expected loading on communications, given the greater information requirements of SAR imagery. A reduced rate of changes in movement from stationary to moving and vice versa also reduces the loading on analysts by lessening the need for SAR to be employed for classification and to a lesser extent for mensuration.

These experiments do not cover all possible interactions. For example we have not considered what may happen when the proportion of targets to vehicles increases, nor have we considered more complicated bursts of vehicle appearances. The experiments do not consider modifications to the baseline CONOPS beyond timing changes, although such modifications could easily be considered. For example, increasing the number of tasks that may be interrupted, changing who completes which task and altering the CONOPS completely. We also do not consider the effect of simply changing the numbers within the crew and altering the proportions of operators.

The next section addresses this latter point: we consider the scenario with 500 potential targets and examine, given the existing assumptions, how many crew would be needed to prosecute targets in under an hour.

4. MC2A Crew Structure

The experiments in the previous section gave an indication of the scope of possible interaction changes that may occur. The aim was to exercise a wide variety of changes to see how dramatic the effects are when modifying the expected scenario parameters. The experiments were also made with a limited number of potential targets available for prosecution, simply due to the computational load of running a large number of simulations. The stated scenario, however, requires the processing of around 500 vehicles initially identified as being potential targets by HRR GMTI. More specifically we are interested in the capability of an MC2A aircraft, for example, to undertake the C2 requirements. We thus now consider the crew composition that would be required to process 500 potential targets. We can then get an indication of whether the MC2A would be able to cope with the full kill chain prosecution for such a scenario, given our idealised assumptions.

4.1 Experimental Design

We assume the same conditions as the base case for the previous experiments, with 500 vehicles instead. All the CONOPS, task timings, vehicle proportions, appearance rates and movements are kept the same. The aim in this experiment is to consider variations to the crew composition to reduce the average kill-chain processing time for targets to below one hour. We do this by iterative modification to the crew composition from the baseline used in the previous section. Our decision on what operator numbers to change is directed by the size of the normalised wait-periods for each operator, adding further operators to reduce the wait-time. This is calculated by totalling the amount of time that is spent by all vehicles waiting for a specific operator type. For example, the wait time for Analysts is the amount of time spent by individual detections waiting to be assessed, having a request for SAR performed, being mensurated and so on. This number is normalised by dividing by the number of those operators to give a wait time per operator of each type. For example, in the base case for analysts we divide by 15. The figures are the averages across 20 trials. Such a search method is not guaranteed to result in an optimal crew but will result in an indicative composition. Further work may be considered to explore the region of crew composition by varying experimental parameters. What this does give us is an indication of how variations may affect the loading on other operators.

4.2 Results

We begin by using the results from the previously run trial (see §3.2) of 500 vehicles as our base case for analysis. The progressive crew modifications, beginning with this base case, depend on the results from the previous trial (see Table 8). The stopping criterion for the entire experiment is when the average target kill-chain is under an hour (see Figure 15). The kill-chain wait-times attributed to each operator role give the indication of where to place the next addition to the crew (see Figure 16). These three illustrations need to be examined in conjunction to get a thorough picture of the experiment. Complete results are presented in §B.5.

Table 8: Progression of crew size modifications

Operator	Base	1	2	3	4	5
Analyst	15	24	24	24	28	32
Analyst Coordinator	3	4	4	4	4	4
Sensor Controller	3	3	3	4	4	4
Strike Controller	3	3	3	3	3	3
Mobile Target Coordinator	1	1	2	2	2	2
Total Analysis Crew	25	35	36	37	41	45
Base case analysis						
Increase Analyst teams and Analyst team size						
Additional decision making capability						
Additional Sensor Controllers						
Increase Analyst team size						
Increase Analyst team size						

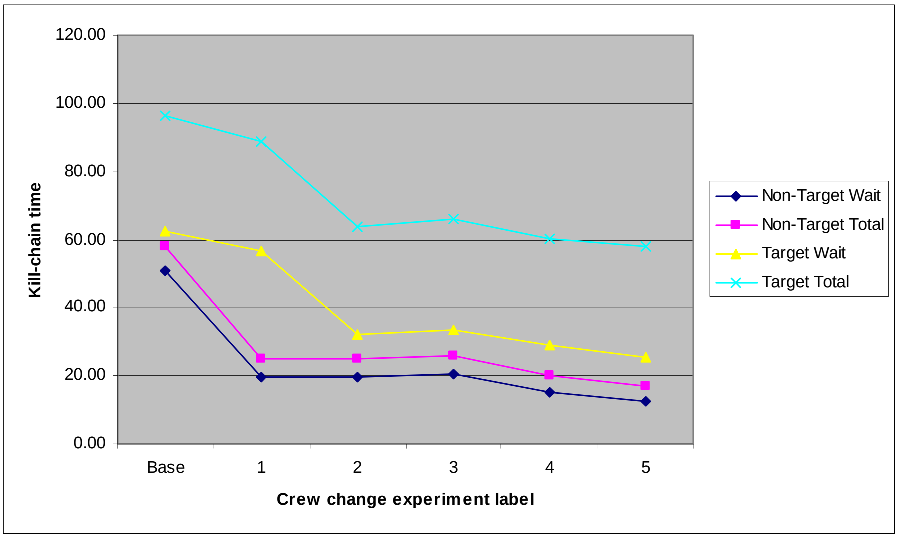

Figure 15: Average kill-chain time per target and per non-target vehicle

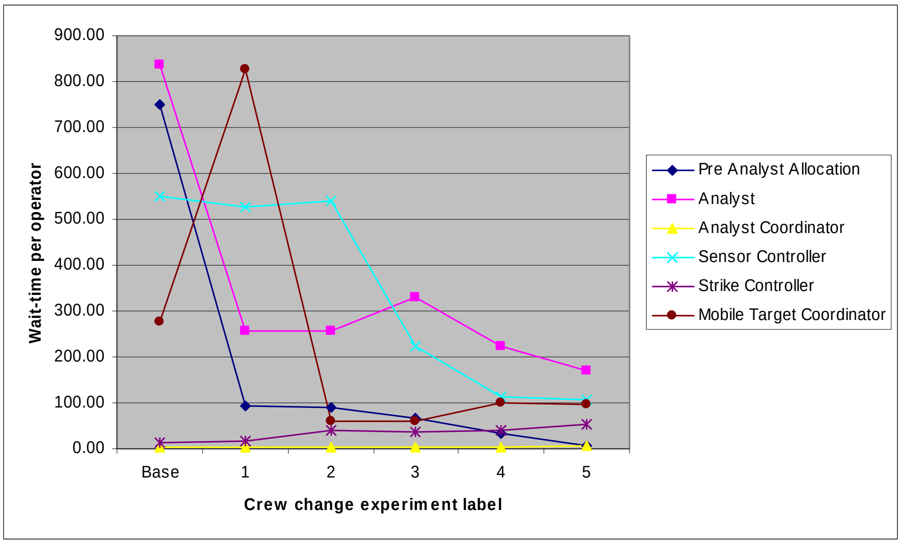

Figure 16: Kill-chain vehicle wait-times normalised per operator

The base case shows large kill-chain wait-times contributed to by the Analysts, Sensor Controllers and to a lesser extent the MTC. The greatest delay is attributed to the Analysts, even without factoring in delays in allocating vehicles for analysis. This is not unexpected given the nominal make-up of the crew; the number of analysts is inadequate for the task at hand. The total simulation time is nearly five hours for three hours of vehicle observation, and each target has over an hour with no operator action. The resulting kill-chain times are excessive.

Experiment 1 increases the number of Analysts by adding another analyst team with a new AC, and increasing the size of each team from five to six. This sees an immediate reduction in the overall time of the tasking, and reductions in kill-chain wait-times per vehicle. The time spent waiting for Analysts reduces three-fold, and the time spent waiting for Analysts allocation reduces eight-fold. There is also a secondary reduction in the amount of SAR work required of the Sensor Controllers. The increase in analytical capability results in a nearly three-fold increase in MTC wait-times.

Experiment 2 adds another MTC to reduce the MTC wait-time: we have two ACs reporting to each MTC for this experiment. This obviously decreases the MTC workload, decreases slightly the overall scenario time, and results in commensurate reduction in the kill-chain processing for targets. The wait-time attributed to the MTCs is reduced tenfold, and the quicker decision-making results in a slight increase in wait-time attributable to the Strike Controllers.

Experiment 3 considers the addition of one further Sensor Controller. The Sensor Controller wait-times are reduced, as is the workload, but at the expense of increasing the wait-times for the Analysts as sensor work is completed more rapidly thus requiring Analyst response sooner. We find ourselves in the situation yet again where the Analysts have the highest wait-times.

Experiments 4 and 5 consider further incremental increases to the analyst team sizes. In experiment 4 there is a decrease in the wait-times attributed to the Analysts and also the SAR Sensor Controllers, while resulting in increased wait-times attributed to the MTC positions and an overall time increase. The experiment 5 Analyst team increase results in dropping the total kill-chain time for targets below one hour, with Analyst wait-time dropping further and the pre-allocation wait-time reducing almost to zero. The lessening of the load on the Sensor Controllers and the Analysts also results in a decrease in the failure rate for SAR operations.

4.3 Discussion

Under the set of conditions for this experiment we see that a greater number of analysts are required than were initially allocated, and that the rate of analysis requires increased decision-making support. The speed of analysis does influence the requirements on SAR imaging, resulting in decreased Sensor Controller loadings. When we achieve our goal of less than 60 minute kill-chains the workload on each of the crew is less than 100 minutes across the final 250-minute scenario. This does not investigate the non kill-chain workload, but it does indicate the need to carefully manage the workloads on operators. Under-loading the crew may be as damaging to concentration as overloading is to performance. The final structure of the crew may influence expectations of numbers needed in an MC2A crew design.

As mentioned previously, the series of experiments presented here provide only a rough indication of the interactions between different operator roles. The results may be highly dependent on the given CONOPS and timings. The final crew make-up may not be optimal either: there may be alternate arrangements requiring less crew that achieve the same results. The high rate of initial contacts would also increase the number of analysts required. Additional roles being included on the aircraft may place further pressures on crew stations. This does not, of course, examine the benefits of having an MC2A on station: it is tougher to disrupt line of sight communications, and in a challenged environment, the MC2A may be more reliable in terms of communications and could be a good backup for any CAOC TCT in the event of long-range communications disruptions.

5. Conclusions

In this paper we have undertaken two main exercises: firstly developing components of a CONOPS including strategic influences, and operational roles and tasks; and secondly developing a simulation of the CONOPS employment in specific scenarios to illustrate delays caused by operator overloading. The development of the CONOPS was based on available USAF documents, including operationally tested CONOPS. Although this paper did not go into the minutia of how tasks are conducted, the specified CONOPS does give a complete structure for the operational requirements. In fact, for the level of detail required for this work, such "how" information would be superfluous. Although the CONOPS may require modification, it gives us a baseline from which to further examine the consequences of specific operational implementations.

The simulation capability presents a best-case analysis of the use of the CONOPS. The dependence on a large number of assumptions — number of vehicles, time of appearance, rate of change of movement, number of operators and command structure, the tasks performed by each operator, the length of time of each task, and so on — means that the relation between the specific results and a final operational CONOPS is tenuous. The value of these experiments is in determining the rough causal links between variables, how specific delays influence the overall completion of the TCT role, and stimulating discussion into whether these characteristics will have operational consequences or whether they are spurious results, possibly based on ill-formed CONOPS specifications.

This work was conducted during a secondment to RAND Corporation, and had the United States Air Force (USAF) as the original customer. However the methodology has broader application to other forces and to differing contexts. Overall the benefits of this approach to CONOPS development and testing are:

- To encourage the development of complete CONOPS for undertaking specific tasks thus determining whether the definition is logically complete and thus generally plausible.
- To consider the CONOPS specifics through particular assets for a particular scenario to determine whether the scenario solution is feasible under a static instantiation.
- To allow the execution of the specific CONOPS using particular crews to give a rough indication of whether the CONOPS is dynamically feasible given the scenario constraints.

These are all important steps in informing whether the CONOPS and associated assets are a viable solution to the tasks presented in a range of scenarios.

5.1 Further Work

There are a number of avenues for further work related to the specifics of the CONOPS developed here: simply making the CONOPS more realistic. Assumptions related to the experimental design — such as on the number of vehicles, their appearance timings, the

number of targets, and so on — may be varied to examine the robustness of the CONOPS beyond the limited scope presented here. Modifications to the CONOPS structure, such as expanding the details of the combat process, may be required as the presented CONOPS is idealistic. For example, the process of sensor fusion is not considered under the current CONOPS, but this may be useful in certain circumstances and the time cost of performing such fusion may be included. Further, the time ranges may be more appropriate if allowed to be Normal or Poisson in nature. Justification for this would be required but it may improve the realism of overall estimates of time delays.

Beyond this, a more general modification to the CONOPS and the simulation would be the inclusion of classification error rates for the different sensor systems and the development of CONOPS around the failure or simple non-performance of the sensors. Assuming that a task would be repeated if failed, we may be able to model such failure simply by modifying the time ranges of the tasks. However, if we wish to include the handling of miss-classification and non-classification specifically within the CONOPS, further work will need to be undertaken. This may still be done without reference to geographical constraints with estimates of performance, and would provide an avenue for exploring the biggest area of concern not addressed within this paper: the ability of the CONOPS to cope with failure.

Finally we may extrapolate from the experimental results to determine the likely loading on communication networks. For example, in the scenario of the MC2A aircraft employment we have indicated what messages and information would need to be distributed between entities. Modelling the CONOPS has given us a proportion of sensor employment in each case as well as the expected delays, and this information may be used to determine the load on communication infrastructure. For the MC2A aircraft, as well as determining whether the crew size for a particular mission is viable, the communications loading will give an indication of the robustness of the communications system.

6. References

Hura, M, McLeod, G et al, *Information for the Warfighter: Integrating C2 and ISR*, 2000, RAND Project Air Force, DB-267-1-AF, classified secret.

Hura, M, McLeod, G et al, *Enhancing Command and Control of Air Operations Against Time Critical Targets*, 2002, RAND Project Air Force, MR-1496-AF.

Jensen, K, "A Brief Introduction to Coloured Petri Nets", *Tools and Algorithms for the Construction and Analysis of Systems*. E. Brinksma (ed.). Proceeding of the TACAS'97 Workshop, Enschede, The Netherlands 1997, Lecture Notes in Computer Science Vol. 1217, Springer-Verlag 1997, 203-208.

Keithley, H, "Space Based Radar Utility Analysis", DSC FY02 Study Task 1 (DSC 02-1), Volume III *Tracking Gap Analysis*, Joint C4ISR Decision Support Center.

Naikar, N, Pearce, B, et al, "Designing Teams for First-of-a-Kind, Complex Systems Using the Initial Phases of Cognitive Work Analysis: Case Study", *Human Factors*, vol. 45, no. 2, pp202-217, Summer 2003.

USAF white paper: "Global Strike Task Force CONOPS", Version 2.0, July 26 2002.

USAF white paper: "Space and C4ISR Capabilities CONOPS", Version 8.1, September 29 2003.

Vick, A, Moore, R et al, "Aerospace Operations Against Elusive Ground Targets", 2001, Chapter Four, *New Concepts for Defeating Mobile Missiles*, RAND Project Air Force, MR-1398-AF.

Appendix A: Tabular Information

The following sections detail in tabular form for completeness the same information as is presented graphically through the result sections of this paper. Each section covers an individual experiment and contains four tables presenting the following information:

- "Average kill-chain total and wait-times prior to operator action": both the total kill-chain time and the wait-time component averaged over all vehicles of each type. This differentiates between targets (true) and non-target (false) vehicles.
- "Average kill-chain operator workloads and total simulation time": gives the average workload of each operator type, plus gives the average total simulation time for comparison.
- "Average per operator total vehicle wait times prior to operator action": this gives the total amount of time spent by all vehicles waiting for a particular operator type to perform some action. Hence the total time spent waiting is averaged by the number of each operator type. Note that there is also listed the "pre analyst allocation" that refers to the time spent waiting for the analyst coordinator to allocate a vehicle to an operator. This is separated as the inhibitor is not only the analyst coordinator's workload but also each individual analyst's limit on the number of concurrent tasks.
- "Proportion of sensor usage": this simply gives the proportion (percentage) of either GMTI or SAR classification or mensuration. The percentages given for the failures — including abandoned SARs, abandoned geo-rectification and interrupts — are in terms of the number of attempts at SAR usage.

A.1. Changes in Decision Making

The strike decision time is altered from 1-5 minutes to 5-10 minutes to 10-15 minutes.

Table 9: Average kill-chain total and wait-times prior to operator action (minutes per vehicle)

Potential Targets		1-5	5-10	10-15
False (95%)	Wait Prior	19.4	19.0	19.6
	Total	24.7	24.3	24.9
True (5%)	Wait Prior	62.3	37.6	30.5
	Total	104.3	74.5	61.7

Table 10: Average kill-chain operator workloads and total simulation time (minutes)

Operator Type	1-5	5-10	10-15
Total simulation time	248.4	244.9	233.3
Analyst	101.9	100.6	101.4
Analyst Coordinator	25.0	25.3	24.8
Sensor Controller	69.2	66.8	67.7
Strike Controller	49.5	49.2	50.2
Mobile Target Coordinator	185.2	113.7	43.5

Table 11: Average per operator total vehicle wait times prior to operator action (minutes)

Operator Type	1-5	5-10	10-15
Pre Analyst Allocation	60.4	50.4	63.2
Analyst	322.3	323.7	318.7
Analyst Coordinator	2.3	3.0	3.3
Sensor Controller	76.8	78.8	82.2
Strike Controller	1.4	4.4	11.9
Mobile Target Coordinator	474.2	116.8	9.5

Table 12: Proportion of sensor usage (percentage)

<table>
<tr><th colspan="2">Vehicle Movement</th><th>1-5</th><th>5-10</th><th>10-15</th></tr>
<tr><td rowspan="3">Vehicle Classification (100%)</td><td>GMTI classification</td><td>82.9</td><td>83.3</td><td>83.0</td></tr>
<tr><td>SAR classification</td><td>17.1</td><td>16.7</td><td>17.0</td></tr>
<tr><td>Abandon prior to SAR</td><td>9.6</td><td>8.9</td><td>8.3</td></tr>
<tr><td rowspan="6">Target Mensuration (5%)</td><td>GMTI mensuration</td><td>67.7</td><td>69.7</td><td>68.3</td></tr>
<tr><td>SAR geo-rectification</td><td>32.3</td><td>30.3</td><td>31.7</td></tr>
<tr><td>Abandon prior to SAR</td><td>0.0</td><td>3.2</td><td>1.7</td></tr>
<tr><td>Abandon prior to geo-rectification</td><td>10.1</td><td>8.9</td><td>4.2</td></tr>
<tr><td>Geo-rectification interrupt</td><td>14.7</td><td>14.5</td><td>13.6</td></tr>
<tr><td>Combined geo-rectification failure</td><td>24.8</td><td>26.6</td><td>19.5</td></tr>
</table>

A.2. Changes in GMTI Performance

GMTI classification performance is altered from 1-2 minutes to 1-5 minutes to 5-10 minutes for completion.

Table 13: Average kill-chain total and wait-times prior to operator action (minutes per vehicle)

Potential Targets		1-2	1-5	5-10
False (95%)	**Wait Prior**	52.3	19.0	9.3
	Total	62.7	24.3	12.3
True (5%)	**Wait Prior**	62.2	37.6	30.6
	Total	101.9	74.5	62.9

Table 14: Average kill-chain operator workloads and total simulation time (minutes)

Operator Type	1-2	1-5	5-10
Total simulation time	295.9	244.9	226.8
Analyst	191.5	100.6	59.3
Analyst Coordinator	25.4	25.3	25.0
Sensor Controller	117.6	66.8	41.7
Strike Controller	49.6	49.2	50.6
Mobile Target Coordinator	113.0	113.7	111.8

Table 15: Average per operator total vehicle wait times prior to operator action (minutes)

Operator Type	1-2	1-5	5-10
Pre Analyst Allocation	201.5	50.4	35.9
Analyst	828.5	323.7	141.8
Analyst Coordinator	2.0	3.0	3.8
Sensor Controller	108.6	78.8	61.6
Strike Controller	2.8	4.4	8.1
Mobile Target Coordinator	41.1	116.8	203.4

Table 16: Proportion of sensor usage (percentage)

Vehicle Movement		1-2	1-5	5-10
Vehicle Classification (100%)	GMTI classification	69.0	83.3	89.9
	SAR classification	31.0	16.7	10.1
	Abandon prior to SAR	5.8	8.9	10.6
Target Mensuration (5%)	GMTI mensuration	64.7	69.7	78.7
	SAR geo-rectification	35.3	30.3	21.3
	Abandon prior to SAR	1.6	3.2	2.4
	Abandon prior to geo-rectification	8.2	8.9	7.1
	Geo-rectification interrupt	3.3	14.5	15.3
	Combined geo-rectification failure	13.1	26.6	24.7

A.3. Changes to Vehicle Numbers

Vehicle numbers are increased from 100 to 300 to 500 in total. 5% are targets, 60% of the total appear immediately.

Table 17: Average kill-chain total and wait-times prior to operator action (minutes per vehicle)

Potential Targets		100	300	500
False (95%)	**Wait Prior**	4.9	19.0	51.0
	Total	9.2	24.3	57.9
True (5%)	**Wait Prior**	4.9	37.6	62.7
	Total	40.3	74.5	96.4

Table 18: Average kill-chain operator workloads and total simulation time (minutes)

Operator Type	100	300	500
Total simulation time	198.0	244.9	290.4
Analyst	29.0	100.6	203.9
Analyst Coordinator	8.2	25.3	41.6
Sensor Controller	13.1	66.8	174.0
Strike Controller	16.6	49.2	84.2
Mobile Target Coordinator	37.0	113.7	188.8

Table 19: Average per operator total vehicle wait times prior to operator action (minutes)

Operator Type	100	300	500
Pre Analyst Allocation	0.0	50.4	751.6
Analyst	31.8	323.7	835.2
Analyst Coordinator	0.9	3.0	4.8
Sensor Controller	3.5	78.8	548.5
Strike Controller	0.4	4.4	12.5
Mobile Target Coordinator	2.8	116.8	278.2

Table 20: Proportion of sensor usage (percentage)

Vehicles Numbers		100	300	500
Vehicle Classification (100%)	GMTI classification	90.8	83.3	72.6
	SAR classification	9.2	16.7	27.4
	Abandon prior to SAR	2.1	8.9	15.1
Target Mensuration (5%)	GMTI mensuration	59.0	69.7	84.4
	SAR geo-rectification	41.0	30.3	15.6
	Abandon prior to SAR	0.0	3.2	8.8
	Abandon prior to geo-rectification	0.0	8.9	7.8
	Geo-rectification interrupt	0.0	14.5	6.9
	Combined geo-rectification failure	0.0	26.6	23.5

A.4. Changes to Vehicle Movement Rate

Vehicle changes in movement are altered, from moving to stationary and vice versa, to occur on average every 15, 30, 45, 60 and 120 minutes.

Table 21: Average kill-chain total and wait-times prior to operator action (minutes per vehicle)

Potential Targets		15min	30min	45min	1hr	2hrs
False (95%)	**Wait Prior**	24.2	21.7	20.1	19.0	15.3
	Total	30.9	27.9	26.0	24.3	19.7
True (5%)	**Wait Prior**	33.9	29.0	31.0	37.6	22.4
	Total	70.9	62.3	64.6	74.5	52.3

Table 22: Average kill-chain operator workloads and total simulation time (minutes)

Operator Type	**15min**	**30min**	**45min**	**1hr**	**2hrs**
Total simulation time	240.2	229.0	218.3	244.9	243.8
Analyst	119.5	111.7	106.7	100.6	83.7
Analyst Coordinator	24.8	25.1	25.2	25.3	24.9
Sensor Controller	106.6	86.9	75.9	66.8	35.1
Strike Controller	49.7	49.8	51.0	49.2	48.4
Mobile Target Coordinator	112.6	114.0	110.1	113.7	112.2

Table 23: Average per operator total vehicle wait times prior to operator action (minutes)

Operator Type	**15min**	**30min**	**45min**	**1hr**	**2hrs**
Pre Analyst Allocation	68.8	58.5	68.6	50.4	56.7
Analyst	353.6	340.4	311.4	323.7	245.9
Analyst Coordinator	2.4	2.8	2.0	3.0	3.1
Sensor Controller	328.3	184.3	131.1	78.8	14.8
Strike Controller	4.6	5.3	5.4	4.4	3.4
Mobile Target Coordinator	69.5	63.8	87.0	116.8	107.9

Table 24: Proportion of sensor usage (percentage)

Vehicle Movement		**15min**	**30min**	**45min**	**1hr**	**2hrs**
Vehicle Classification (100%)	GMTI classification	75.3	77.5	80.0	83.3	90.7
	SAR classification	24.7	22.5	20.0	16.7	9.3
	Abandon prior to SAR	32.7	17.1	11.6	8.9	0.7
Target Mensuration (5%)	GMTI mensuration	81.0	92.3	85.3	69.7	89.0
	SAR geo-rectification	19.0	7.7	14.7	30.3	11.0
	Abandon prior to SAR	14.9	4.7	1.7	3.2	0.0
	Abandon prior to geo-rectification	26.7	25.0	5.1	8.9	5.3
	Geo-rectification interrupt	23.0	34.4	18.6	14.5	7.9
	Combined geo-rectification failure	64.6	64.1	25.4	26.6	13.2

A.5. Modifying MC2A Crew Structure

Refer to Table 8 in section 4 for an explanation of the different experiment labels (Base, and 1 to 5).

Table 25: Average kill-chain total and wait-times prior to operator action (minutes per vehicle)

Potential Targets		**Base**	**1**	**2**	**3**	**4**	**5**
False (95%)	**Wait Prior**	50.97	19.85	19.75	20.66	15.19	12.29
	Total	57.92	24.98	24.92	26.09	20.08	16.95
True (5%)	**Wait Prior**	62.66	56.80	32.27	33.57	29.01	25.38
	Total	96.41	88.94	63.91	66.12	60.32	58.18

Table 26: Average kill-chain operator workloads and total simulation time (minutes)

Operator Type	**Base**	**1**	**2**	**3**	**4**	**5**
Total simulation time	290.4	254.7	242.7	241.9	262.0	245.4
Analyst	203.9	99.5	99.9	104.5	82.0	69.8
Analyst Coordinator	41.6	31.6	31.5	31.2	31.5	31.0
Sensor Controller	174.0	95.0	95.0	79.8	61.6	58.3
Strike Controller	84.2	85.0	82.7	84.6	82.6	85.3
Mobile Target Coordinator	188.8	188.9	93.8	93.4	93.9	93.1

Table 27: Average per operator total vehicle wait times prior to operator action (minutes)

Operator Type	**Base**	**1**	**2**	**3**	**4**	**5**
Pre Analyst Allocation	751.59	92.79	91.29	65.04	33.48	6.72
Analyst	835.23	256.30	255.02	331.11	221.92	170.59
Analyst Coordinator	4.75	3.43	3.00	3.80	4.81	5.34
Sensor Controller	548.45	527.18	540.53	224.79	112.64	105.94
Strike Controller	12.53	15.77	41.25	36.50	39.60	52.87
Mobile Target Coordinator	278.20	827.50	59.28	61.18	100.18	96.85

Table 28: Proportion of sensor usage (percentage)

Vehicle Movement		Base	1	2	3	4	5
Vehicle Classification (100%)	GMTI classification	72.6	85.4	85.6	83.3	86.9	88.2
	SAR classification	27.4	14.7	14.4	16.7	13.1	11.8
	Abandon prior to SAR	15.1	19.9	21.4	13.0	10.2	8.7
Target Mensuration (5%)	GMTI mensuration	84.4	92.6	89.6	90.2	91.8	79.0
	SAR geo-rectification	15.6	7.4	10.4	9.8	8.2	21.0
	Abandon prior to SAR	8.8	10.6	7.9	9.9	0.0	1.7
	Abandon prior to geo-rectification	7.8	21.2	11.8	12.3	5.9	6.8
	Geo-rectification interrupt	6.9	12.1	11.8	17.3	13.7	1.7
	Combined geo-rectification failure	23.5	43.9	31.6	39.5	19.6	10.3

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE Time Critical Targeting Concept of Operations (CONOPS) Interactions	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)
4. AUTHOR(S) Sam Waugh and Carl Rhodes	5. CORPORATE AUTHOR DSTO Defence Science and Technology Organisation 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-2543	AR-014-987	Technical Report	May 2011

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
2010/1014970/1	N/A	N/A	46	8

DSTO Publications Repository	14. RELEASE AUTHORITY
http://dspace.dsto.defence.gov.au/dspace/	Chief, Air Operations Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

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16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CITATION IN OTHER DOCUMENTS Yes

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Air operational CONOPS simulation

19. ABSTRACT
In this paper, we consider Concept of Operations (CONOPS) for engaging Time Critical Targets (TCTs) and quantify the feasibility of those CONOPS. The process involves defining the scope of the CONOPS, developing a plausible TCT CONOPS based on existing practices, and simulating the dynamics of the CONOPS to obtain a better understanding of the inherent interactions within such a complex, dynamic and concurrent system involving people, sensors, and computational processing. Further, we consider a case study of the undertaking of the complete TCT CONOPS from a Multi-Sensor Command and Control Aircraft (MC2A) and the implications for crew structure. This work should be of interest to those working on TCTs, Command and Control (C2) systems, and surveillance and reconnaissance issues. While the examples presented here are USAF-centric, the techniques proposed should be applicable to a wide range of C2 problems where response time is a critical factor.